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The Prevention of Industrial Lead Poisoning in English Factories

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SOME RESULTS OF AN INVESTIGATION INTO THE EFFICIENCY OF LINEN WEAVERS*

H. C. WESTON

Investigator to the Industrial Fatigue Research Board

THE fact that long-continued work in a hot and humid atmosphere is physiologically detrimental has led to the institution of inquiries in the textile trades in order to regulate conditions of work so as to safeguard the health of the workers. As a result regulations have been imposed in Great Britain based largely upon evidence taken from employers and workers, having regard, on the one hand, to conditions regarded as necessary for securing economic production and, on the other hand, to the effects experienced by the workers when employed under these conditions. When the regulations were being formulated, consideration was also given to observations upon the body temperature of a large number of operatives at work in textile mills, and to the results of experiments designed to determine the effects upon the human organism of work comparable with that performed in the factory, but done under similar atmospheric conditions reproduced in the laboratory.

*Received for publication Jan. 19, 1923.

More recently, investigations have been initiated by the Industrial Fatigue Research Board with the object of determining, by studies of the output of a fairly large number of workers, during a long period, the extent to which the working capacity of cotton, silk and linen weavers is affected by the special atmospheric and other conditions under which they work. In this paper some of the results obtained relating to linen weavers are discussed.[1]

During a period of six months, from July to January, hourly records of output were obtained by means of pick-counters fitted to forty looms in each of two weaving sheds situated in the North of Ireland. Except in a few cases, each weaver operated two looms so that the records obtained represent the work of about fifty weavers. Simultaneously with the reading of the pick-counters, records of the wet and dry

[1]These results are fully discussed, and the complete data presented, in Report No. 20 of the Industrial Fatigue Research Board, 1922, "A Study of Efficiency in Fine Linen Weaving" by H. C. Weston.

bulb temperatures were taken from hygrometers placed in the vicinity of the looms comprising the observational groups. From the data thus obtained curves have been plotted representing the hourly, daily, and weekly variations of output or efficiency, as well as of temperature and humidity, from which certain conclusions can be drawn as to the relation of the former to the latter. Information regarding the relation of output to other variables is also afforded by study of miscellaneous data obtained during the investigation. The principal results obtained, which concern the relations between output, temperature, lighting, and hours of work, are dealt with in this communication.

The Influence of Temperature on Efficiency

The production of fine linen cloth, such as cambric, is greatly facilitated if the atmosphere of the weaving shed is at a fairly high temperature and has also a high degree of humidity. This fact has long been recognized by manufacturers, and experiments have shown that, within reasonable limits, the higher the temperature the better the output, with regard to both quantity and quality, while the same is true of humidity practically up to the point of saturation (1).

Nevertheless, since the human factor is one of the agents of production, in practice it is only possible to attain technically ideal atmospheric conditions provided that they fall within the limits imposed by the physiological requirements of the worker. The determination of those atmospheric conditions which, owing to their effects both on the work and on the worker, are such as to secure maximum production is, therefore, a matter of equal importance to manufacturer and weaver alike. If these conditions are not identical with those believed to be ideal from the purely technological point of view, the manufacturer must not go beyond them, since any physical advantage gained will be counteracted by impairment of the weavers' working capacity.

During the present investigation the relative humidity in both sheds was maintained practically constant at 88 per cent., while the velocity of the air varied so little that, in considering the relation of atmospheric conditions to the variations of efficiency observed, only variations of wet bulb temperature need be taken into account. The hourly variations of these two variables throughout a composite or typical day are shown for each shed in Figure 1.

A marked similarity is apparent in the shape of the curves of efficiency and those of temperature, the rise of efficiency being practically coincident with that of temperature up to the middle of the afternoon spell, thus suggesting the existence of a definite relation between these two variables. This similarity is not so marked during the afternoon in the case of Shed B, but while the general level of temperature in both sheds is practically the same, the general level of efficiency is considerably higher in Shed B than in Shed A; the shape of the afternoon efficiency curve in the former shed is, therefore, probably determined to a considerable extent by fatigue. The effect of the continuous rise of temperature throughout the day is to give the afternoon spell a productive superiority over the morning spell. This is clearly shown by the data given in Table 1, and holds good for every day in the week, except in two periods when the afternoon efficiency is slightly lower on the

last day of the week. As will be seen from this table, the total period covered by the investigation was divided, by changes in the number of working hours, into four sub-periods in Shed A and into two sub-periods in Shed B. In Figure 1, however, the curves of hourly variation

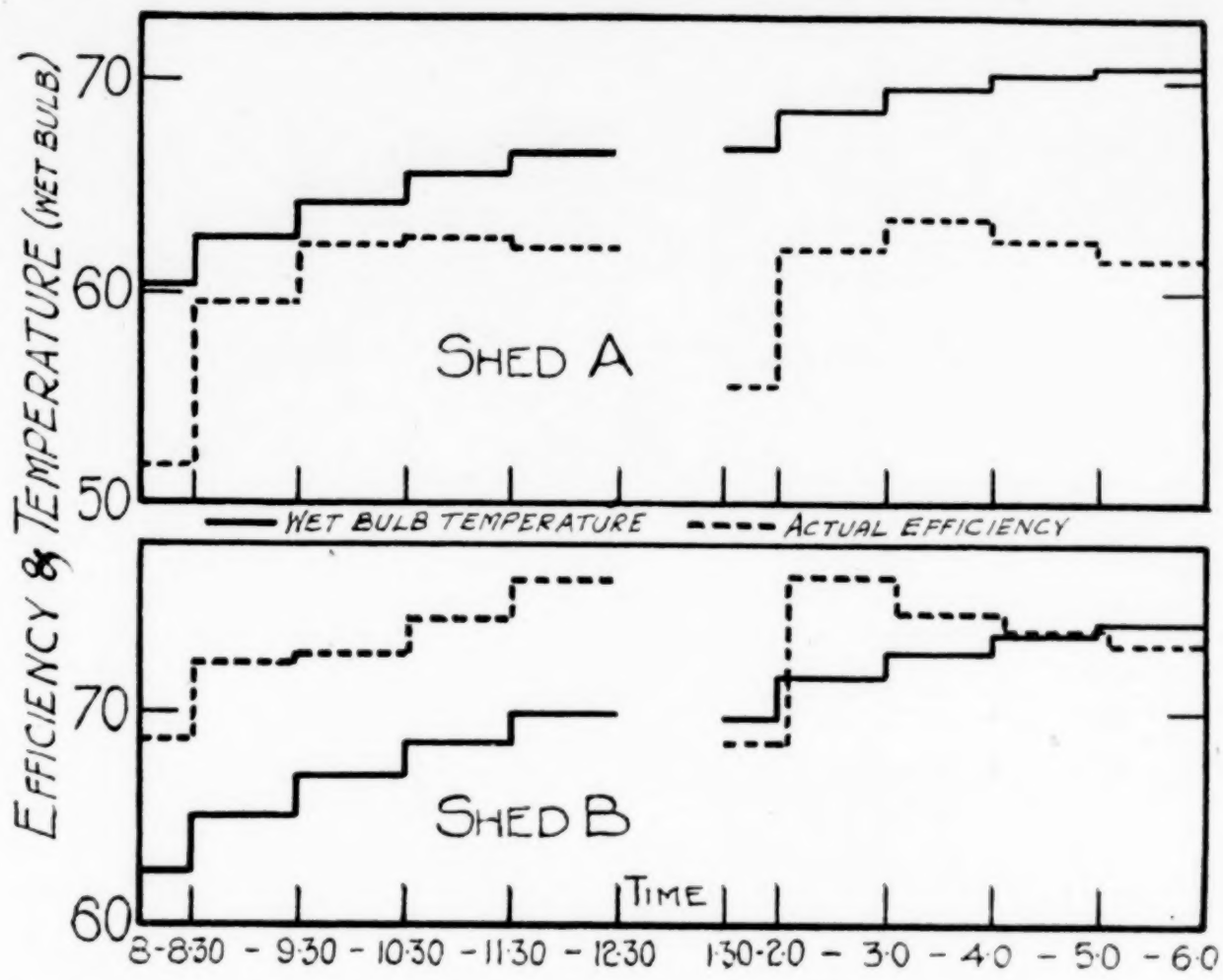

FIG. 1.—Hourly variations of temperature and efficiency during a typical day in both sheds.

are shown only for the first of these periods in each shed, as these are typical of the whole of the curves as far as the effect of temperature is concerned.

The curves of temperature and efficiency are plotted for each day of the week in Figure 2; a marked resemblance in the shape of the two curves is again apparent. Correlation of the mean daily efficiency with the mean daily wet bulb temperature during the first three[2] statistical periods of investigation in Shed A, and during the two periods in Shed B, gives positive and significant coefficients of 0.59 and 0.71 for the respective sheds (see Table 2). These coefficients justify the conclusion that, under the conditions obtaining during the investigation, there is a definite and direct relation between the wet bulb temperature and efficiency. Further, the magnitude of the coefficients suggests that, within the limits of variation experienced, the efficiency-temperature curve approximates fairly closely to a straight line, and this is confirmed if the curve is plotted from the series of values correlated. Since then, for practical purposes, efficiency may be regarded as increasing *pari passu* with temperature, a correction to the efficiency data can be applied which will eliminate the effect of temperature. This has been done in the case of curves plotted in Figure 2; the corrected curves shown there will be discussed when the effect of altering the hours of work is considered. A similar correction applied to the data relating to the distribution of efficiency during the day shows that, apart from the in-

[2]The results of the fourth period have not been used because only a small number of observations were made, owing to the shortness of the period and the abnormally short week.

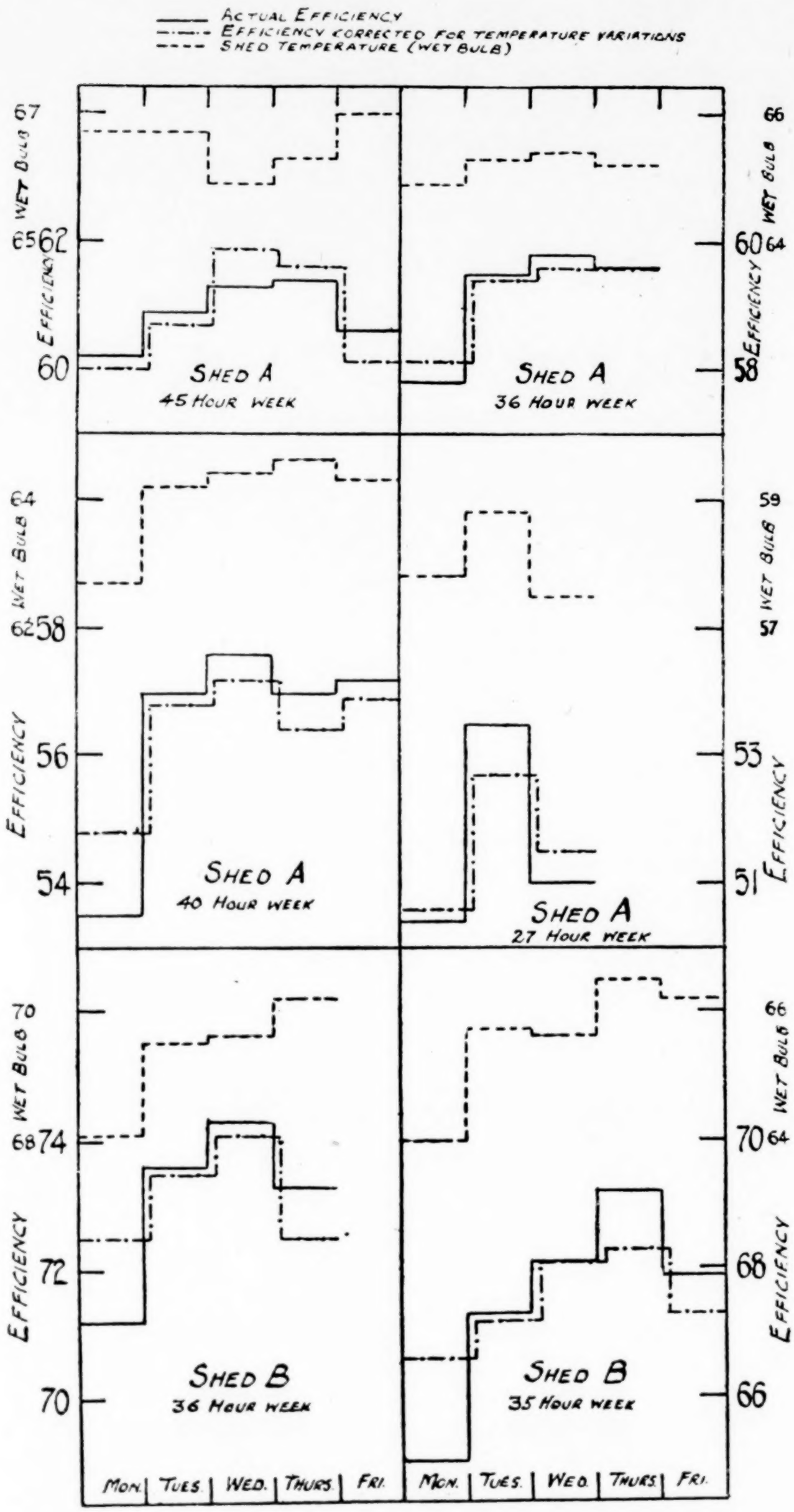

FIG. 2.—Daily variation of efficiency and temperature.

TABLE 1.—DIURNAL VARIATION OF EFFICIENCY AND TEMPERATURE

Period		Monday		Tuesday		Wednesday		Thursday		Friday	
		A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
					Shed A						
45	Efficiency	58.7	61.6	60.4	61.4	61.2	61.5	60.6	62.3	61.0	60.8
hour	Mean var.	1.8	1.3	1.9	2.0	1.0	1.1	1.8	1.5	1.2	0.9
week	W.B. temp.	64.1	69.2	64.0	69.4	63.5	68.3	63.6	69.0	64.1	69.9
36	Efficiency	55.5	59.2	57.9	61.0	58.1	61.5	58.9	60.2	—	—
hour	Mean var.	2.1	1.0	1.5	1.6	1.6	1.4	3.2	1.4	—	—
week	W.B. temp.	62.1	67.7	62.7	68.0	62.6	68.2	62.7	67.7	—	—
40	Efficiency	51.4	55.8	55.3	56.8	57.2	58.0	55.5	58.7	57.2	57.4
hour	Mean var.	2.5	2.1	1.7	2.6	2.6	2.2	1.8	1.9	1.5	3.0
week	W.B. temp.	61.1	64.7	62.7	66.0	62.6	66.7	62.4	67.3	62.2	67.0
27	Efficiency	49.0	51.8	52.2	54.7	50.9	51.1	—	—	—	—
hour	Mean var.	1.2	1.2	0.8	1.5	1.1	1.7	—	—	—	—
week	W.B. temp.	56.1	59.4	56.7	60.7	55.4	59.5	—	—	—	—
					Shed B						
36	Efficiency	70.6	71.8	73.0	74.2	73.9	74.7	73.6	73.0	—	—
hour	Mean var.	1.8	1.4	1.4	1.2	1.2	1.6	1.3	1.7	—	—
week	W.B. temp.	65.0	71.2	66.8	72.1	66.5	72.6	67.2	73.1	—	—
35	Efficiency	62.3	67.7	66.4	68.1	66.0	70.1	67.2	71.1	66.9	67.8
hour	Mean var.	1.6	2.6	2.4	3.3	1.9	3.0	1.6	2.9	1.4	3.6
week	W.B. temp.	63.0	64.9	65.3	66.1	65.3	65.9	66.0	66.9	66.2	66.1

TABLE 2.—CORRELATION OF EFFICIENCY WITH WET BULB TEMPERATURE IN SHEDS A AND B

	Shed A		Shed B	
	Efficiency %	W.B. Temp.	Efficiency %	W.B. Temp.
Mean	58.5	65.3	70.3	67.7
Mean variation	±2.37	±1.97	±3.22	±2.36
Standard deviation	2.98	2.38	3.86	2.83
Number in series	70		82	
Sum of products of corresponding individual deviations	294.53		635.69	
Coefficient of correlation	+0.59		+0.71	
Probable error of coefficient	±0.058		±0.037	

fluence of temperature, efficiency is lower during the afternoon than during the morning spell.

The normal diurnal variation of temperature in the sheds insures that, as a general rule, production is greater during the afternoon than during the morning spell, but during the hottest week of the whole period of investigation, and only during this week, the afternoon production on each day fell below that of the morning. (See Fig. 3.) No unusual factor, apart from temperature, could be discovered as operating during this particular week, and the important conclusion is therefore suggested that the effect observed is due to the fact that the afternoon wet bulb tempera-

ture, which exceeded 74° F., reached a level so inimical to the comfort and fatigability of the weavers as to counteract any physical advantage gained by improvement in the weaving qualities of the yarn.

This conclusion is supported by similar results obtained on five isolated days during the investigation in Shed B. Three of these days were Thursdays, when a slight fall of efficiency during the afternoon spell was a normal occurrence, but the significance of the results lies in the fact that on these Thursdays the fall is considerably greater than usual and increases as the excess of wet bulb temperature over 73° F. increases. The two remaining days were a Monday and a Wednesday when the afternoon temperature exceeded 73° F., and these results are even more striking since, with a lower wet bulb temperature, the afternoon efficiency on these days of the week, particularly on Mondays, was invariably higher than that of the morning.

The economic limit of temperature for fine linen weaving is therefore attained when the wet bulb reaches, at the most, 75° F. Even then, production falls if work is done for any length of time at this temperature, in spite of the fact that the weaving qualities of the yarn are improved, and may continue to improve even at higher temperatures. As a working limit, advantage would probably accrue to both weaver and manufacturer if the wet bulb could be prevented from exceeding 70° F., except for very short periods; but under existing conditions, in normal summer weather, the temperature of the sheds is frequently in excess of this figure.

Haldane found that, when work comparable to that involved in weaving was done, and light summer clothing worn, discomfort was experienced when the wet bulb reached 73° to 74° F. (1, p. 38). He suggests a maximum permissible wet bulb temperature of 75° F. for weaving sheds, but regards 70° F. as the desirable maximum. These figures cor-

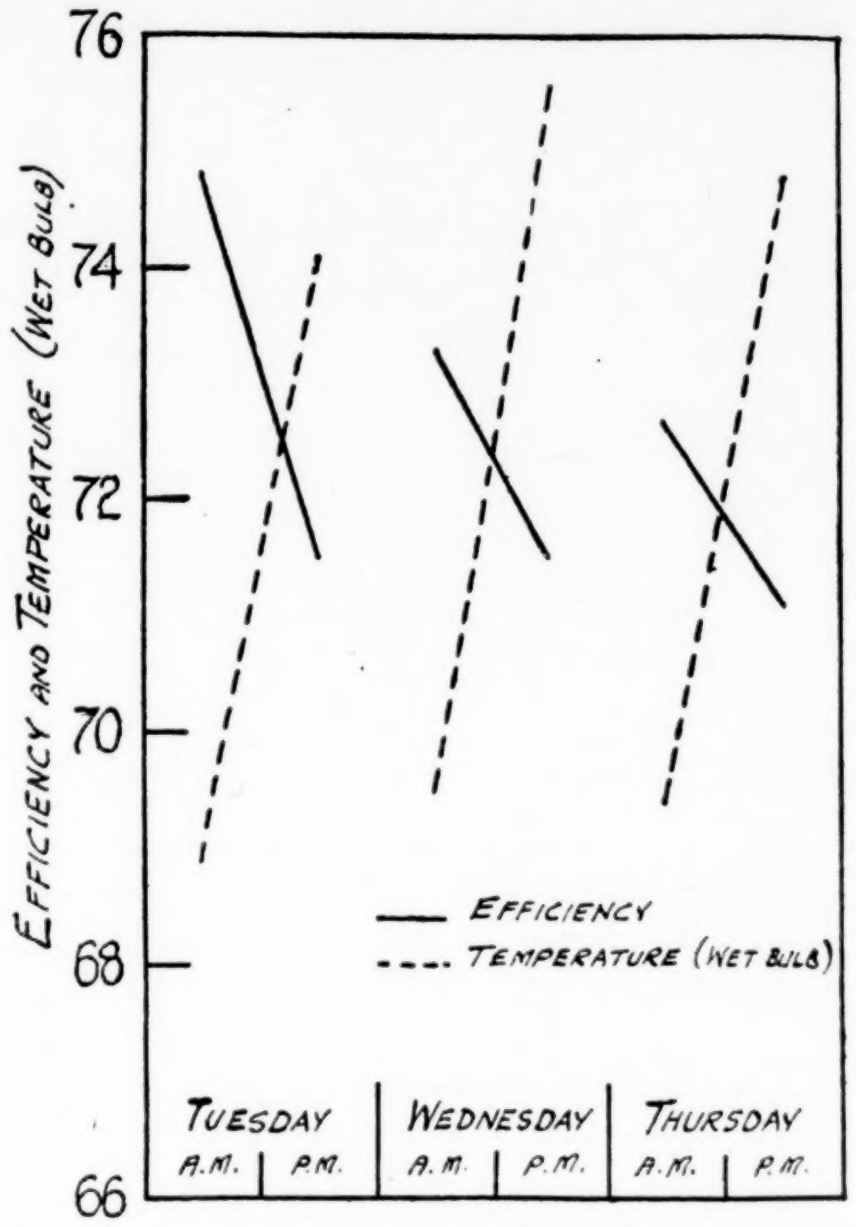

FIG. 3.—Diurnal variation of efficiency and temperature during a hot week.

respond with those suggested by the results discussed above, but Hill (2) considers them to be very high unless there is ample movement of the air—a condition seldom found even in modern weaving sheds. At similar wet bulb temperatures, Legge (1, p. 41) has shown that the body temperature of linen weavers begins to rise above the normal, while in the case of cotton weavers Collis and Pembrey (3) found the surface temperature of the face from 4° to 13° F. higher with a wet bulb of 71° F. than with the wet bulb temperature of about 55° F. found in the weav-

ers' homes. Considering, then, the conclusions reached by these investigators, together with the data presented in this paper, and having regard to the physical effects of high temperature in facilitating the work of the linen weaver, regulation of the shed temperature so that the wet bulb seldom exceeds 70° F., while maintaining the present average humidity, should safeguard the health of the weaver and insure maximum production.

The Influence of Lighting on Efficiency

There is a growing recognition of the importance of lighting, with regard to both adequacy and suitability, as a factor affecting the efficiency of the industrial worker, yet few attempts have been made to measure, in terms of output, the effect of any given conditions of lighting. Recently, however, Elton (4) has shown that the efficiency of silk weavers falls below its daylight value by 10 per cent. when work is done by artificial light, even if the amount of illumination is adequate. Further data are now available illustrating this effect of artificial light, and also showing the effect of inadequate daylight on the efficiency of linen weavers.

During the last two weeks of one of the periods of investigation in Shed A the looms were stopped as soon as the daylight illumination of the shed became so poor that it rendered the continuance of work difficult. The effect of carrying on the work with inadequate illumination even for a short time, however, is shown by the curves plotted in Figure 4, in which the hourly variations of efficiency are shown separately for the first three and the last two weeks of the period.

Here the normal fall of the curve during the last hour of the day is considerably accentuated when the illumination provided is inadequate, the actual loss of efficiency occurring as the result of the failing daylight being 6.5 per cent. A similar but greater effect is disclosed by the results obtained during a subsequent week, these being also shown graphically in Figure 4; the fall of efficiency during the last hour is roughly 11.5 per cent. in excess of the normal fall when daylight illumination is adequate. From data available regarding the average daylight illumination at the time to which the results discussed relate, the general illumination of the shed when work was stopped was estimated to be about 2 foot-candles.

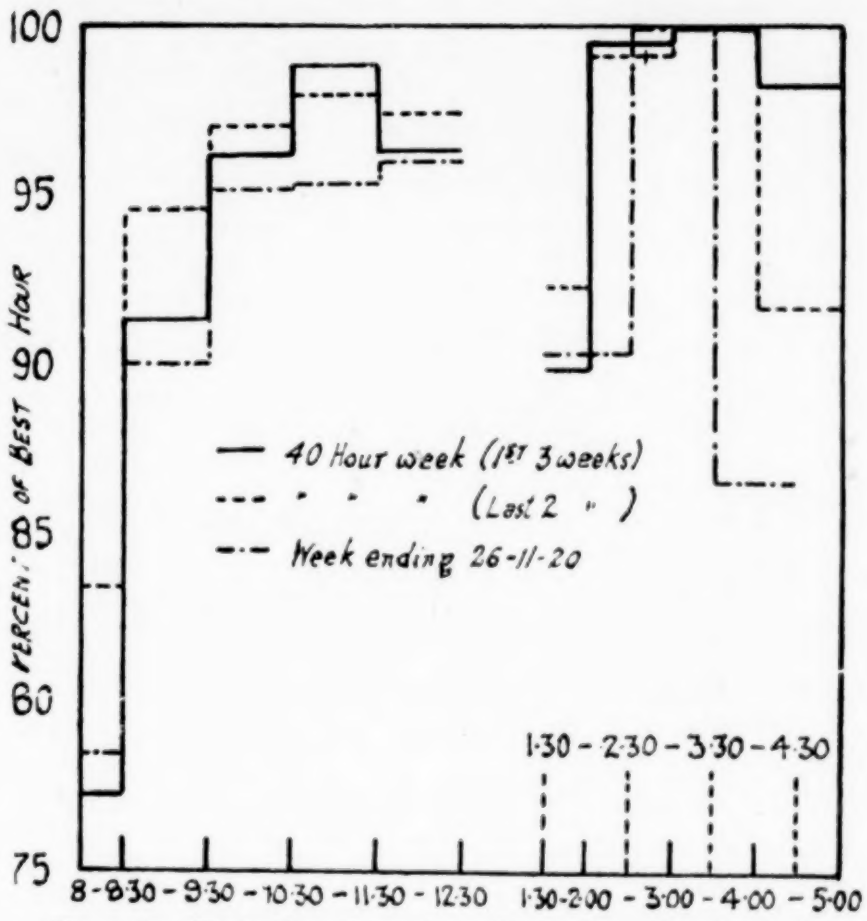

FIG. 4.—Relative hourly efficiency (typical day) for the beginning and end of the forty-hour period and for the week ended Nov. 26, 1920 (Shed A).

During one of the periods of investigation in Shed A artificial light had to be used during practically the whole of the first hour of the day and also during the last two hours, from 4.15 to 6 P.M. No effect of its use was observed during the morning, probably because the illumination was augmented by the contin-

ually increasing daylight; but during the last two hours in the afternoon it effected a reduction of efficiency roughly of from 7 to 10 per cent. of the normal daylight value. A slight increase of efficiency occurred during the last hour of the day, and this suggests that the effect of artificial light upon efficiency may be most marked during the first hour of its use, and that some improvement is to be expected when the weavers become accustomed to the change of lighting.

The efficiency curve during a week in December (see Fig. 5) shows a fall of 21.5 per cent. in the last hour of the day, and a large proportion of this fall can be attributed to the use of artificial light. A marked fall of the curve is also seen during the preceding hour and is due largely to inadequate daylight. On the average, when work is done under artificial light, as provided in Shed A, efficiency falls below its daylight value by about 11 per cent.; this conclusion agrees substantially with that formed by Elton in the case of silk weavers working under very similar conditions of lighting.

The method of lighting employed in Shed A consists entirely of local lights, each loom being provided with a metal filament lamp in a shallow conical metal reflector, suspended approximately at the head level of the weavers. Generally speaking, the amount of illumination provided is adequate for the kind of work, the maximum varying between 5 and 8 foot-candles. At the selvedges and back of the looms, however, the illumination is reduced to between 1.5 and 2 foot-candles, which is hardly sufficient to render the detection of breakages at these parts as easy as it should be if a high standard of efficiency is to be maintained. Probably, however, the reduction of efficiency which occurs under artificial light is due principally to glare, shadow effects, and the absence of general lighting. The common type of shallow conical reflector does not screen the filament of the lamp and, with the latter suspended at head level immediately in front of the worker, considerable glare is experienced which must fatigue the eyes and increase the difficulty of perceiving breakages of the yarn. The weaver has also to make continual changes of adaptation, since he has to scan the whole area occupied by his warp, parts of which are in shadow and receive much less illumination than the cloth-fell immediately in front of him. The effect of glare is also accentuated by the excessive contrast between the bright illuminant in the central line of vision and the surrounding darkness of the shed; moreover, when artificial illumination is provided entirely by local lights, efficiency may also be affected indirectly owing to the fact that

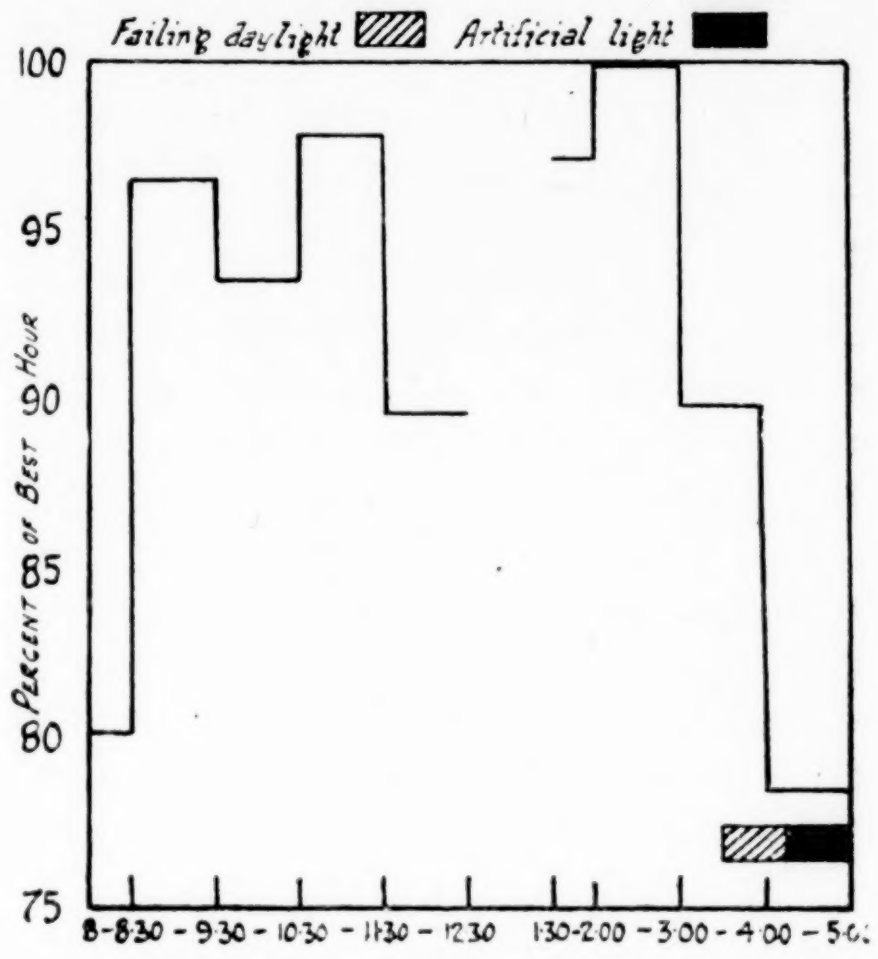

FIG. 5.—Relative hourly efficiency (typical day) for week ended Dec. 3, 1920 (Shed A).

the general darkness of the surroundings exerts a depressing effect upon the workers.

Recent experiments (5) tend to confirm the view that excessive contrast between illumination at the point of work and the surroundings is undesirable. Considerably less efficiency might be lost under artificial light if good general lighting were substituted for local lighting, or if local lighting were supplemented by a certain amount of general illumination; the latter alternative is the most practicable in factories where machinery is driven by overhead belting. Glare can, of course, be eliminated, either by raising the lamps well above the line of vision (using units of higher intensity, so that the illumination on the work is not reduced) or by effectively screening them so that the filament is normally invisible to the workers.

The Influence of Hours of Work on Efficiency

Several changes in the number of hours worked were made during the course of the investigation under consideration; the details are given in Table 3.

The relative efficiency (after correction for hourly variations of temperature) throughout the typical day in each period is plotted in Figure 6. The curves afford some evidence in support of the contention recently put forward by Bedford (6) that an ideal work-curve should approximate to a straight line. It will be observed that the first two curves, relating to Shed A, represent efficiency during a nine-hour day, and are very similar. The slightly increased irregularity of the curve during the four-day week is probably not so much an effect of shortening the week as an effect of the reason for this shortening—namely, that slackness of trade necessitated weaving for stock, and the need for consistent effort by the weavers was therefore not so apparent as under normal circumstances. The fourth curve, representing a nine-hour day, is also similar to the first two as far as the morning spell is concerned, but the further shortening of the week, with the consequent increased reduction of the weavers' earnings, is probably responsible for stimulating efficiency during the first half of the afternoon spell—an effect which would have been more apparent during the latter half of the spell if work had not had to be done under artificial light during the last two hours. The third curve, showing efficiency during an eight-hour day in a five-day week, is the most regular and shows the closest approximation to the ideal work-

TABLE 3.—CHANGES IN NUMBER AND DISTRIBUTION OF HOURS OF WORK

Shed	Period	Duration (Weeks)	Date	No. of Hours per Week	No. of Days per Week	Morning Spell	Afternoon Spell
A	1	5	7/26 to 8/27/20	45	5	8.00—12.30	1.30—6.00
	2	5	8/30 to 9/30/20	36	4	same	same
	3	5	10/11 to 11/12/20	40	5	"	1.30—5.00
	4	3	12/20 to 1/12/21	27	3	"	1.30—6.00
B	1	11	8/ 3 to 10/14/20	36	4	8.00—12.30	1.30—6.00
	2	8	10/25 to 12/17/20	35	5	same	1.30—4.00

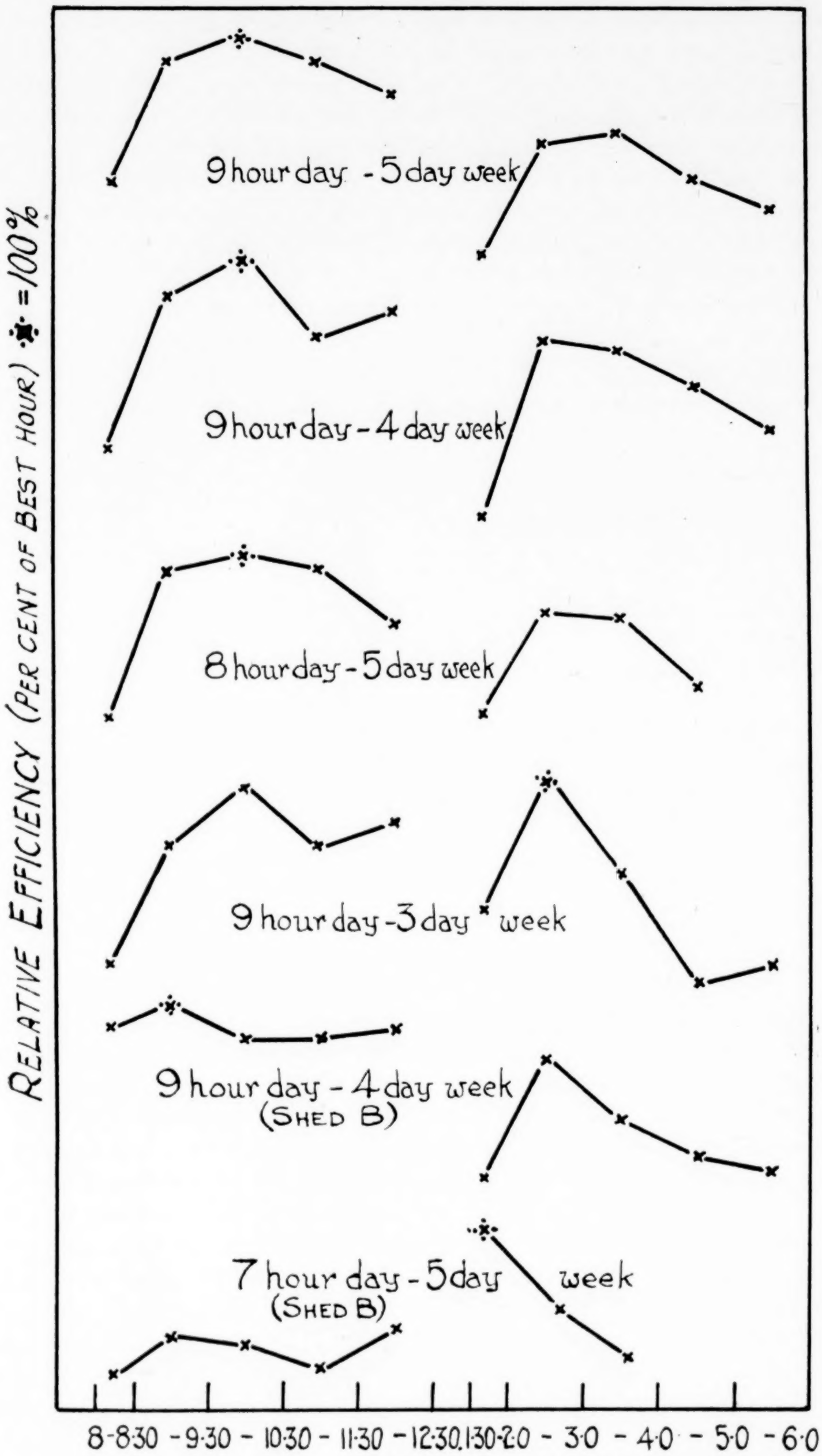
RELATIVE EFFICIENCY (PER CENT OF BEST HOUR) ·✱· = 100%
9 hour day - 5 day week
9 hour day - 4 day week
8 hour day - 5 day week
9 hour day - 3 day week
9 hour day - 4 day week (SHED B)
7 hour day - 5 day week (SHED B)
8-8.30 - 9.30 - 10.30 - 11.30 - 12.30 1.30 - 2.0 - 3.0 - 4.0 - 5.0 - 6.0

FIG. 6.—Relative efficiency throughout typical day for different work periods in both sheds.

curve, especially when it is remembered that the fall of the curve in the last hour of the day is accentuated by the results obtained during the last two weeks of the period when work at this time was hampered by inadequate daylight.

The curves relating to Shed B show interesting differences from those of Shed A. During the morning spell there is a much closer approximation to an even maximum, and a number of factors other than hours of work, were probably responsible for this result. Among these may be mentioned good time-keeping, close supervision of the workers, and good organization of the work, while the standard of skill of the weavers, the quality of the yarn used, the method of humidification adopted (employment of underground instead of overhead ducts), and the treatment of the yarn before and during weaving, probably contributed in producing the effect observed. In the case of the nine-hour day, the high standard of efficiency, sustained with remarkable regularity throughout the morning, is not maintained during the afternoon spell when a fairly rapid fall of the curve occurs after the first hour and a half. With the seven-hour day and the longer week, practically the same regularity is noticeable during the morning spell, although the level of the curve is much lower in relation to that of the afternoon spell owing to the wholly unusual occurrence of the maximum efficiency during the half hour following the midday break. This unusual feature appears to be an effect of the reduction of hours; the very short duration of the afternoon spell probably encouraged a prompt start and a special effort by the weavers, which might have been better maintained but for the effect of diminishing daylight illumination—the factor which determined the length of the spell.

Ignoring the curve for the wholly abnormal period when work was done on only three days, the corrected curves representing efficiency throughout the week, plotted in Figure 2, show a general tendency to become more regular, and to rise steadily from day to day, as the total number of hours worked is reduced.

On the whole, although the data presented are not conclusive, they suggest the general conclusion that reduction of hours of work, within reasonable limits, tends to produce a better type of work-curve. Apart, however, from any increase of uniformity in the distribution of output effected by changing the hours of work, the effect of such changes upon the total output must be considered. In the present case, the hours of work were reduced with the object of effecting a reduction of output, and not with the object of increasing production by reducing fatigue; but in spite of this, so far as can be estimated after allowing for the effect of temperature variations, shortening the length of the working day did not result in a proportional reduction of total output.

Summary

(*a*) When the relative humidity is constant, the productive efficiency of fine linen weavers varies directly with the wet bulb temperature up to a certain critical point. This connection between efficiency and temperature is principally due to the favorable influence of the latter upon the weaving qualities of the yarn, but when the wet bulb reaches 73° to 75° F. it becomes definitely unfavorable to the weavers, and produces undue fatigue and reduction of efficiency. As a working maximum, a wet bulb temper-

ature of 70° F. should insure maximum production consistent with the comfort and health of the weavers.

(*b*) When work is done under artificial lighting conditions, such as those described, efficiency falls below its daylight value by about 11 per cent. This loss might be reduced if glare were eliminated and uniformity of illumination secured. The provision of a system of general, as well as local, lighting would prevent excessive contrast between illumination at the point of work and the surroundings, and would secure a closer approximation to daylight conditions than is possible if local lights only are employed.

(*c*) Reasonable reduction of the number of hours of work appears to favor the production of a uniform work-curve, and is not accompanied by a proportional reduction of total output.

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J. I. H.
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OBSERVATIONS ON DYSMENORRHEA OCCURRING IN WOMEN EMPLOYED IN A LARGE DEPARTMENT STORE*

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DYSMENORRHEA from the industrial viewpoint is that discomfort or pain accompanying menstruation which lessens the efficiency of women employees. The crippling of women in industry from this cause necessitates practical consideration by the industrial physician.

This study is based on 2,077 consecutive physical examinations of women employees in a large department store which maintains an average working force of 3,000 women. These examinations were made in the year 1921 and in the early months of 1922. Each employee was carefully questioned as to discomfort, pain, loss of time necessitated by her menstrual period and the methods, if any, usually employed in securing relief. Each card was marked according to the following classification:

0. Those who experience no discomfort.

Those who feel a slightly lowered efficiency, but who do their work without complaint.

1. Those who begin work and later are compelled to seek relief from a hot drink, medication, or rest on a couch or bed with hot water bottles, etc.

1.2. Those who occasionally remain at home or go home during the first day of the period, but at other periods suffer little or moderate pain or discomfort.

2. Those who are compelled to remain at home one or more days of each menstrual period.

A.M. Menopause resulting from operative procedures.

N. M. Menopause resulting from natural causes.

The following classification was made on the basis of the histories obtained from the examination of 2,077 women between the ages of 16 and 60:

	0	1	1.2	2	A. M.	N. M.
Married	520	148	27	28	13	65
Single	737	398	64	63	0	14

An analysis of this classification shows that 60 per cent. of the working women between the ages of 16 and 60 are able to continue their work uninterruptedly during their menstrual periods, suffering little if any discomfort. With this group may be placed those who have no menstruation, owing either to post-operative artificial menopause or to the natural cessation. Hence 65 per cent. may be considered not handicapped by the menstrual function.

Among 26.3 per cent. of these women there is a slightly lowered efficiency due to pain or to other discomfort which necessitates mild remedies or rest on a couch or bed for a short time. This group can be, and is being materially benefited by education along the lines of health and hygiene. It is with this group that the industrial hospital is most concerned.

The ninety-one women in Group 1.2, who are occasionally incapacitated, may be materially helped by the methods applicable to Group 1.

Group 2, in which there are also

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ninety-one women, presents the real industrial handicap. According to my findings the women of this group represent about 4.4 per cent. of industrial women. They are unable to work after employing some of the common remedies or even after a few hours in bed with hot applications, and must stay home from work one or more days each month. They present some gross pelvic pathology or endocrine disturbance, which requires concentrated study with the applicable medical or surgical treatment. This is a problem to be solved without the industrial hospital and until it is solved the person should be considered in the industrial world as any other cripple.

Management of Dysmenorrhea Cases

It is the policy of the medical department of this store to aid in every way to raise the efficiency of the female employees during menstruation.

1. Talks on hygiene of the menstrual period are given by the physician to the sponsors, or representative women, of the store, each of whom is personally in charge of a group of women. These sponsors are chosen because it is very difficult to assemble such a large body of women employees for purposes of instruction. They are the disseminators of the store knowledge in matters pertaining to their groups of employees; hence they are made the disseminators of knowledge concerning the hygiene of the menstrual function. In addition, with each physical examination a short personal talk applicable to the individual type of period is given, together with advice as to the proper mental attitude toward this function, its hygiene, etc.

2. A nurse is in attendance at all times and hot drinks, suitable medication, hot water bottles, with rest in bed when necessary, are given to those who seek relief. At the end of a two hours' rest at the most, the patient is usually able to return to work.

3. The more difficult cases and the repeaters have access to the physician for consultations.

4. Medical passes are issued only in the exceptional cases. These passes are "on pay" and the attitude of the department is to do everything for the comfort of the employee, hoping to get her back on the job, rather than to issue passes by request. This attitude eliminates Group 2 from our observation to a certain degree.

Analysis of the Hospital Records on Dysmenorrhea

Analysis of the hospital records on dysmenorrhea for the period of six months from June 6, 1922, to December 6, 1922, shows that 199 women out of a total of 3,000 made 238 visits to the hospital for the treatment of dysmenorrhea; 108 of this number came for hot drinks or medication, and ninety-one desired to lie down, in addition. Of these twenty-eight were repeaters; seventeen came for medication only, and eleven were so ill that they had to lie down. The number of visits made by these repeaters was as follows:

For Medication

13 reported 2 times.
2 reported 3 times.
1 reported 5 times.
1 reported 6 times.

For Medication and Rest in Bed

9 reported 2 times.
2 reported 3 times.

The amount of time spent in the hospital in six months for dysmenorrhea was 120 hours and thirty-five minutes. This loss is less than 0.003 per cent. of

the time given by women as employees, but is an individual loss in efficiency to these ninety-one women of 0.4 per cent.

The foregoing figures show that during this period of six months only 6 per cent. of the women employees reported to the hospital for treatment, whereas earlier records showed that 26 per cent. needed medication, etc., during their menstrual periods. Of the remaining 20 per cent. some have probably been benefited by the talks, and by the attitude of the hospital; some may have prescribed their own analgesic or else may have been under the treatment of the family physician. In either event, the employee is at work in the store.

Statistics regarding the women who stay at home during menstruation occasionally, and even every period, were exceedingly difficult to obtain. I present the following figures simply for their face value. Two departments in the store, the employees of which were the least transient, were selected—one a selling department, and the other non-selling. The time sheets were secured from May 22, 1922, to September 16, 1922, a period of almost four months. On these sheets absences of a duration of three or more days were noted as vacation, leaves, and sickness. Absences of one or two days' duration were noted as for personal reasons. These records were then studied for periodicity of absences.

Non-Selling Department

112 women employees with 106 single day absences without a periodicity:	
35 absent 1 day	35
10 absent 2 or 3 consecutive days at one time only	25
15 absent several non-consecutive days at no regular interval	46
Total	106

Selling Department

47 women employees with 24 single day absences without a periodicity:	
8 absent 1 day	8
4 absent 2 or 3 consecutive days at one time only	10
3 absent several non-consecutive days at no regular interval	6
Total	24

Hence 0.9 per cent. of the working time of the 112 women in the non-selling department was lost in absences; some of this time, it is reasonable to suppose, was due to dysmenorrhea. Among the forty-seven women in the selling department 0.5 per cent. of the working time was lost in absences for similar reasons. These figures give an average loss of 0.7 per cent. The actual loss due to dysmenorrhea, then, is less than 0.7 per cent. among these groups of women. From the lack of periodicity in these records it may be concluded that the women absent from dysmenorrhea belong to the classification Group 1. 2. It is this group that the industrial physician must reach and, by education and regulation of hygiene, must keep at work every day.

Where is Group 2 in this store? The attitude of the medical department is probably responsible for eliminating this group. The individual talks at the time of the examination and subsequent consultations with the physician have probably helped a few women. The others are discontinued in the turnover of labor because of their periodic absences.

Summary and Conclusions

1. The great majority of women suffer no appreciable lowering of efficiency during the menstrual function. According to this study based on 2,077 consecutive examinations of women employees in a large department store, 65 per cent. had no menstrual handicap; 30.6 per

cent. had a slight menstrual handicap; whereas only 4.4 per cent. were seriously handicapped.

2. Much can be done to overcome the lowered efficiency of women in industry by education and by the proper management of the industrial hospital.

3. The attitude of the hospital does much toward overcoming the habit of not working during the menstrual function.

4. The women employees who must remain at home every period because of severe disability should be considered in the industrial world as any other handicapped person. The question whether they should or should not be employed is a debatable one, but their disability should not be charged against the great majority of working women among whom lowered efficiency as a result of menstruation is negligible.

THE PREVENTION OF INDUSTRIAL LEAD POISONING IN ENGLISH FACTORIES*

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In spite of the general knowledge concerning the dangers of lead poisoning in various industries, this disease continues to occur to a fairly large extent in persons handling lead products, and it accounts for a considerable mortality. When it is appreciated that for every fatality there are from ten to thirty cases which may be recognized clinically, and that in each of these the period of disability may be prolonged for several months or longer, it becomes apparent that the total economic loss due to this disease must assume large proportions. It has been estimated that among house painters the attack rate may be as high as one per thousand employed, and that in some industries the rate may be considerably higher.

It was the privilege of the writer, during the summer of 1922, to study in some detail the methods employed in England for the prevention of lead poisoning in industrial establishments. The results of this study are presented not because they contain new and hitherto unknown facts regarding lead poisoning but because they furnish information which indicates the practical means used in the control of the disease on a nation-wide basis, permitting a comparison of the English methods with the methods used in different parts of the United States. In England, the measures taken for the prevention of this disease, as well as of other similar diseases of occupation, are under the control of the Factory Department of the Home Office which corresponds, in general, to the Department of Labor in most states of the United States.

Figures given by Dr. T. M. Legge, Chief Medical Inspector of Factories (1) show that, in 1920, 243 cases of lead poisoning, with twenty-three deaths, were reported in industries under the control of his department. These figures may be compared with 1,058 reported cases in 1900, with thirty-eight deaths. The comparison of reported cases and deaths during the years 1900 and 1920 is shown in Table 1.

In the registration area of the United States there were, during the year 1920, 120 deaths certified as due to chronic lead poisoning. Such figures, however, by no means indicate the total mortality resulting, directly and indirectly, from this disease. It is common experience that diseases of the kidneys and lungs are frequently associated with lead poisoning, and it is certain that lead plays an important, undoubtedly a very large, rôle in the mortality due to diseases of these organs. The clinical evidence is that the absorption of lead is an important factor in sclerotic changes in the blood vessels and in many other diseases incurred during exposure to lead, and that in such cases deaths are seldom recorded as due to lead poisoning but are ordinarily ascribed to some other cause.

In New York State there are reported annually from fifty to 100 cases of industrial lead poisoning with an average of about eleven deaths. Table 2 gives the industrial figures in that state for a

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period of nine years (2). Based upon these figures it has been estimated that there are in the United States at least 2,000 cases of chronic lead poisoning annually, possibly a much larger number.

Available evidence indicates that the chief means by which lead is introduced into the system is through the respiratory tract, either as fumes or as dust. Part of the lead is no doubt deposited in the mouth and pharynx and swallowed, and part is drawn into the lungs. In some cases lead is introduced into the mouth on the hands and becomes mixed with food, but this method plays a secondary rôle as the cause of disease. A third method, the absorption of lead through the skin is, theoretically, a possible cause of lead poisoning, but if this plays any part at all in the production of clinical symptoms, it must be quite insignificant.

In England during 1919 the total number of cases of occupational disease for which compensation was paid was 10,074, of which 2.3 per cent. were lead poisoning (3). It is officially recognized by the Home Office that women are more susceptible than men and that "industrial plumbism is practically always the result of inhalation and absorption from the alimentary or pulmonary tract, or both, of dust and fumes" (4). Uncleanliness and carelessness on the part of the worker are accepted as contributory causes. Women and young persons are excluded from certain types of industry known to be especially dangerous. In general these processes are associated with the manufacture of lead pigments and the melting or reduction of lead on a large scale. It is further required by law that the employment of women and young persons in processes involving the use of lead compounds shall be permitted only upon the existence of the following conditions:

(*a*) Locally applied exhaust ventilation so as to remove dust and fumes at the point of origin.
(*b*) Cleanliness of tools and workrooms.
(*c*) Notification to Government authorities of all cases of lead poisoning and compensation therefor.
(*d*) Periodic medical examination of persons employed in such processes.
(*e*) Provision of sufficient and suitable cloakroom, washing, and mess room accommodation, and of special protective clothing.
(*f*) Rule against bringing food or drink into the workroom.

Diagnostic Standards

The official statement of diagnostic standards for the detection of lead poisoning in England is not without interest (4). The following symptoms are especially noted:

Blue Line on the Gums.—This by itself is noted as indicating the presence of lead rather than of lead poisoning. It is a valuable sign as a danger signal and affords an indication of the etiology of given symptoms.

Anemia.—The destruction of a certain number of red cells is stated to be the earliest action of lead when absorbed. Facial pallor due to interference with the nerve supply of the blood vessels of the face is noted. In males, anemia is said to be comparatively rare and its significance, especially when associated with loss of subcutaneous fat, particularly noticeable in the orbit and buccinator region of the face of the lead worker, is consequently greater.

Colic.—Digestive disturbances associated with habitual constipation and colic (sometimes with attacks of diarrhea) are noted. It is stated that fully 75 per cent. of the notifications of lead poisoning in England are on account of colic.

J. I. H.
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TABLE 1.—NOTIFICATION OF LEAD POISONING IN GREAT BRITAIN IN 1920 AND 1900

Industry	1920		1900	
	Cases Reported	Deaths	Cases Reported	Deaths
Smelting of metals	45	3	34	1
Brass works	0	0	3	0
Sheet lead and lead piping	3	0	17	1
Plumbing and soldering	6	1	9	0
Printing	9	0	18	2
File cutting	3	1	40	3
Tinning	2	0	5	0
White lead	17	0	358	6
Red lead	11	0	19	0
China and earthenware	24	13	200	8
Electric accumulators	47	2	33	0
Paints and colors	9	0	56	1
Coach building	13	0	70	5
Ship building	9	0	32	2
Other industries	45	3	164	9
Total	243	23	1,058	38

TABLE 2.—CASES OF LEAD POISONING REPORTED TO NEW YORK STATE DEPARTMENT OF LABOR FOR NINE-YEAR PERIOD ENDING AUG. 31, 1920 (2)

Industry	Number of Cases	Number of Deaths
A. *Painting*		
House, structural or ship	273	52
Factory or shop, chiefly automobile and carriage painting	77	12
Total	*350*	*64*
B. *Manufacturing*		
Storage batteries	140	3
White lead, paints, etc.	61	5
Smelting or casting lead, solder, etc.	19	4
Printing	19	4
Wire goods	8	0
Electrical goods	14	2
Brass and copper goods	8	0
Rubber goods	6	0
Tin cans	5	2
Miscellaneous	33	4
Total	*313*	*24*
C. *Plumbing*		
Total	*11*	*2*
D. *Electrical power station*		
Total	*6*	*0*
E. *Miscellaneous or indefinite*		
Total	*30*	*11*
Total	*710*	*101*

Arthralgia.—Severe pain may occur in the region of the large joints, generally the knee, elbow, or shoulder.

Nervous Symptoms.—Vertigo, persistent headache, and symptoms of lead encephalopathy are described in detail. Especial attention is directed to epileptiform seizures which simulate true epilepsy. Mental symptoms are divided into three classes: (1) toxemia with

sensory disturbances which tend rapidly to improve upon removal of the patient from exposure; (2) hallucinations of sight and hearing, more chronic in nature, which may be permanent; (3) symptoms resembling general paralysis with tremors, increased knee jerks, incoordination accompanied by listlessness amounting to dementia, but which tend to disappear.

Paralysis.—"The most frequent pronounced nervous symptom of lead poisoning is the well-known 'dropped wrist,' due to paralysis of the extensors of the fingers and wrist." Other muscles may be involved, and it is noted that the strain to which certain muscles or groups of muscles have been put seems to influence the extent of the paralysis.

Interstitial Nephritis.—Direct inflammation of the vessel walls, resulting in obliterative arteritis, arteriosclerosis, and degeneration and exudation in the kidney, lung, and liver are noted. This inflammation gives rise at a comparatively early stage of albuminuria. Late sclerotic changes in the vessels are mentioned only incidentally.

Medical Examinations

In the prevention of lead poisoning in England, great reliance is placed upon the periodic examination of the workers, particular attention being paid to new workers who are said to be especially susceptible. The procedure is comparatively simple and many examinations may be performed in a short period of time and with only a nominal interruption of work. I have seen an expert examine twenty-five men in less than twenty minutes.

The employees are brought into the office and are examined in turn by the physicians. As may be supposed, the routine examination is in no sense a complete physical examination. The surgeon asks one or two questions as to general health, examines the face and the conjunctivae for evidence of anemia, looks at the gums for the blue line, and tests the extensors of the fingers and the wrist for muscular weakness. The extensor test is described as follows: "The surgeon can examine the outstretched hands by placing the tip of the forefinger of his own in the outstretched hand of the worker and the ball of the thumb upon the extreme tip of each finger, gently pulling it down, noting the spring present in the muscles." It is stated that this is probably the most delicate test for the detection of early extensor paralysis. Only in exceptional cases is there any further examination. In such cases the examination may be complete, including urine and blood tests.

The intervals between examinations vary considerably according to the character of the work done. Where there are particular dangers, as in atmospheres heavily laden with fumes or dust, the examinations may be made weekly. In other parts of the factory where the danger is less, as in the department where finished products are packed, examinations are made less frequently, possibly once every three to six months. Records are kept in all cases.

The surgeon is required not only to make the examinations but to indicate to the employer processes which appear to be unduly dangerous, and to suggest to both the employee and the employer methods which may be used to prevent poisoning. The employee is warned to use every possible effort to insure habits of cleanliness and attention to regulations. In general only those cases are notified which show sufficient symptoms to require abstention from work. The duration of suspension from work rests

upon the discretion of the surgeon. In cases of slight or transient attacks temporary suspension may suffice but in repeated or grave attacks prolonged suspension, or even permanent exclusion from work in lead, may be necessary.

The periodic examinations of employees by examining surgeons permit early and adequate reporting of cases, and thus make it possible for the Factory Department to take precautions against the disease. They also tend to reveal incipient and recurrent cases at an early date, and in this way effectively prevent the continued employment of susceptible persons in a particular occupation for which they are physically, or physiologically, unfitted. The latter benefit is by no means of minor importance. There is no doubt that the intelligent selection of employees for this particular employment according to the individual powers of resistance will do much to prevent industrial disability.

"Industrial disease," says Sir Kenneth Goadby (5) "is undoubtedly a cause of unemployment and, therefore, to decrease unemployment not only should disease be prevented but an attempt should be made to select for employment persons whose specific and individual powers of resistance are best suited for the particular type of employment. In any given industry the variations in employment, possible within the same industry, are very great and a judicious selection of persons for their employment would, no doubt, be a gain not only to the individual himself but to the industry as a whole."

As far as the writer can judge from observation, no serious objection to the work of the inspecting surgeons is made either on the part of the employer or on the part of the employee, but there is a tendency, in the course of the daily routine, to disregard minor precautions for the prevention of poisoning, and especially among the employees there is a disposition to become careless and to neglect ordinary precautions. Constant vigilance and attention to detail on the part of the examining surgeon apparently play an important part in the prevention of the disease.

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ATMOSPHERIC PARTICULATE MATTER: I. DUST, WITH A NEW APPARATUS FOR ITS DETERMINATION

(*Continued*)

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VII. DESCRIPTION OF NEW APPARATUS

The object in view in the design of this new apparatus was to produce an instrument which would be capable of taking samples at various rates up to 8 or 10 cubic feet per minute by a wetting method requiring a small volume of wetting medium; and which would at the same time collect the dust, accurately measure the air flow through the apparatus, reduce to a minimum the time required for field work, and establish a practical method of altering the duration and degree of contact between the particulate matter and the wetting medium.

In the accompanying drawing (Fig. 1), dusty air enters the first collector through the side entrance, passes down through a 1-inch tube, bubbles through the perforated thimble and 80 to 90 c.c. of water, passes up through the scrubber plate, and is spiraled out the top. The second collector functions in exactly the same manner, both being alike and interchangeable. All the metal parts except the vacuum pump are made of standard tubing or sheets of spun brass or copper; and in addition all these metal parts except the pump (of which the housing is aluminium) and the orifice meter are nickel plated on all surfaces. The object of nickel plating is to facilitate cleaning, since it is easier to wash dust off a bright shiny surface than off a dull one. Also, dust remaining on bright metal is more visible than is dust on dull metal. The cap at the top of the 1-inch entrance tube is removable to facilitate washing. The only gaskets necessary are at the junction of the glass bulb and the main tube of the collector. A glass bulb is used, at present, so that the scrubbing effect may be observed, but there seems to be no reason why this bulb cannot be made of spun copper and be plated, thus giving an all-metal collector which will be satisfactory for many dusts. Rubber stoppers on the bottom outlet are preferred to rubber tubes and clamps, since the latter retain too much dust and tend to clog, particularly in samples of the sizes handled by this apparatus. The bottom outlets seem to be of no advantage in the all-metal collectors and will probably be discarded.

Various volumes of water have been used—80 to 90 c.c. are required when using the scrubber plates, otherwise 60 to 70 c.c. suffice. Larger volumes of water require more time in the eventual separation or evaporation of the water, increase the load on the pump during sampling, and add inappreciably to the efficiency of the scrubbing. Water lost by evaporation must be replaced, or the upper holes of the thimble will not be effective. This point will be discussed later.

1. *Thimble.*—The method of altering the contact between the dust and the wetting medium is furnished by thimble holes the size of which, therefore, is not fixed. At first, in order to obtain more uniform air distribution, we used thim-

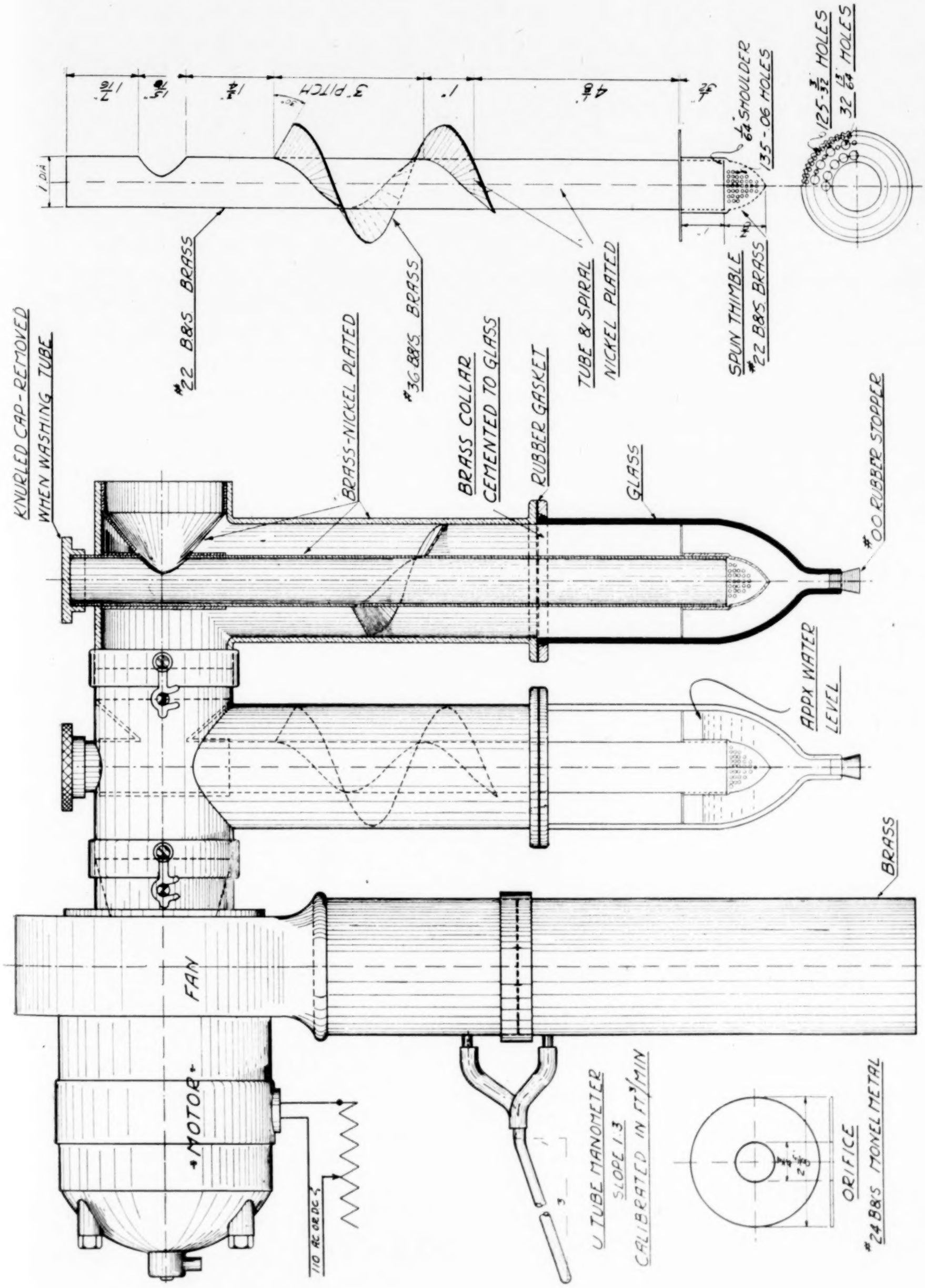

FIG. 1.—Double dust collectors connected to exhaust fan and orifice meter.

bles with holes which increased in diameter from the top of the thimble to the bottom. Thimbles of many shapes have been tried, such as hemispheres, fine screens, cones, etc., all of which can be made by any spinner, as expensive chucks are not required. Those used by us at present are of a convenient shape to spin. By varying the number and size of the holes the size of the bubbles can be altered at will. Small holes are more effective, but they increase the resistance to air flow, reduce the size of the sample, and increase the difficulty in cleaning.

We have never been able to show that it is of particular importance how near the thimble comes to the bottom of the glass tube. As long as there is a space of about three-quarters of an inch between the thimble and tube, the thimble functions properly. It apparently makes little difference whether the bubbles strike against the wetting medium or against the glass. The efficiency of the apparatus, however, is less at speeds where the air flow through the holes is uneven—a condition which applies at speeds of less than 6 cubic feet per minute for thimbles of the size shown. We have also been unable to show that holes increasing in size from top to bottom are an advantage, except for increased ease in cleaning. There is a slight advantage in using slow speeds in that the bubbles are smaller, but this is probably counterbalanced by loss in the velocity at which the bubbles meet the water. It is important to keep the holes separated since, if they are placed too close together, the resulting bubbles join on emerging from the thimble.

2. *Scrubber Plate.*—It was expected that the efficiency of the collectors would be materially increased, owing to increased contact between the bubbles and the wetting medium, by the use of a scrubber plate such as is shown in Figure 1. The holes in the plates are of such size as to allow a partial layer of water to build up above the plate, leaving about an equal amount below, thus giving a twofold scrubbing effect: (1) at the thimble, and (2) at the scrubber plate. By altering the size of the holes in the plate the water distribution can be changed at will. The results obtained, however, showed that the scrubber plate had little or no effect in increasing the efficiency of the apparatus, and, as a consequence, the plates will probably be abandoned.

3. *Spiral.*—Modern air washers, evaporators, and many similar types of apparatus are equipped with devices for avoiding entrainment losses, the underlying principle being to change the direction of the air or gas abruptly. The spiral fulfils this function and has, therefore, been incorporated in our apparatus. Without some such method of avoiding entrainment it was impossible to maintain the necessary air speed unless very long tubes were used. The large tube, into which it is essential that the spiral fits tightly, is made of nickel-plated brass instead of glass, in order to avoid breakage resulting from scratches on the inside of the glass. Furthermore, glass tubes of large diameter frequently vary, in 5-foot lengths, more than one-eighth of an inch in inside diameter, so that spirals for different glass collectors are not interchangeable.

The geometry of the construction of the spiral and its true envelope is not as simple as at first appears. The spiral, cut from thin standard brass sheets, is soldered on the 1-inch brass tube, and both parts are nickel plated. We have found it best to approach, as nearly as possible, a flat spiral, but since it is im-

possible to cut such a spiral from a plane surface, we approximate it by using one which makes an angle of about 30° with the horizontal. The geometric inaccuracy of the method increases rapidly with the decrease in this angle. The distortion of the surface of the spiral caused by soldering on the tube is progressively great with decreasing angles, so that the plating must be done after soldering in order to prevent peeling. Flat spirals could be cast, turned, or possibly twisted and pounded into shape, but the advantage, if any, of so doing would probably not be worth the trouble or expense. Many variations in widths, pitches, and angles have been tried. The type shown, however, has been found to be the most satisfactory and can be made easily and quickly to fit any size cylindrical collector tube.

An unforeseen advantage of the spiral is realized in cleaning the collector. All of us have frequently used the Palmer apparatus in spite of its demonstrated inefficiency for stopping very fine particles, and all confess to have shaken water out of the bulb unintentionally, and entirely through carelessness. The spiral on our collector effectively prevents such an occurrence, provided the tube is held in a vertical position and is shaken up and down. This naturally greatly facilitates cleaning. It seems reasonable to assume that the spiral assists in obtaining intimate contact between the dust and the water in much the same manner as do the eliminators on the exhaust of air washers. The value of this point, however, is questionable since the air passes up the spiral at a rather low speed. It does, however, give an effect comparable to that obtained in the Palmer apparatus, but much more violent and less pulsating, while the entrainment is stopped so effectively that the outlet at the T-connection is dry, even at air flows of 12 cubic feet per minute.

4. *T-Connections and Air Entrance.*—The T-connection is made from standard brass tubing, while the conical shaped portion, through which the dusty air enters, is made of spun copper. The outside of the conical shaped portion is easily cleaned, but the inside is more difficult. The T offers no difficulty in cleaning.

As shown in Figure 1, the upper portion of the spiral ends on the side of the collector opposite the air exit. This causes more efficient separation of the entrained water than if the spiral ended on the same side as the air exit. If a two-hole stopper is used—one hole for the air entrance, and one for the exhaust and slow air flows—the exhaust air bubbles out of the thimble unequally and is pulled toward the exhaust-hole side, since the bubbles tend to take the shortest path. This effect is obviated, however, by using the spiral.

5. *Suction Pump.*—The source of air suction for our device is the motor and fan of a Premium Vacuum Cleaner. The motor, fan, and housing of this apparatus are of rugged construction and yet are light in weight. Furthermore, the motor runs at surprisingly constant but high speeds, requires very little oiling, and is comparatively dust-proof. A sliding contact rheostat is used to control the speed.

6. *Orifice Meter.*—If one aspires to accurate results in the collection and weighing of the dust in air, it is inconsistent to use inaccurate methods for measuring air flow. The pitot tube is objectionable since a straight length of several diameters of pipe is required in order to eliminate the swirling and other effects of curves or elbows. Further-

more, the pin holes used in the static pressure arm of modern pitot tubes become clogged entirely too easily. Venturi meters are not easy to make, while a gas-meter with a capacity of 10 cubic feet per minute is out of the question since it is entirely too large for field use. Electric meters, while more accurate, require additional apparatus.

Having had some experience in the use of the Bailey orifice meter in industrial work, we felt that a small one could be used on our apparatus. Bailey (86) points out, in his original paper, the fact that the accuracy of the orifice meter is independent of bends or elbows, and shows that the error in metering steam is about 1 to 2 per cent. Our experience in the use of this meter for air flow shows a still smaller error. A point which Bailey emphasizes is the location of the pressure taps, particularly the lower one. It is quite inaccurate to measure air flow by this method unless the low pressure tap is placed at the *vena contracta*, where the lines of air flow take the shape of an ideal flow meter. It is likewise essential to use a stiff orifice plate. A factor, based on the ratio of the orifice to the pipe diameter and on the air friction in the pipe, is applied to correct for the difference between the flow through an orifice and the flow through an ideal meter, which takes the true stream-line configuration. A 100 light Tufts Gas-Meter, kindly lent to us by the Boston Consolidated Gas Company, was used to check the theoretical curve shown in Figure 2. This meter, while not so accurate as the wet type, has a very low resistance to air flow of such magnitudes as we were reading, and was calibrated against a large spirometer both before and after our tests. The recording mechanism is so constructed that the speed of the dial hands is uneven and large samples are, therefore, necessary to insure correct readings. Since such a meter measures true volume while the orifice meter measures weight, it is essential that they be connected to work at the same pressure. Whether air is blown through or drawn through by suction seems to make no difference, provided one knows

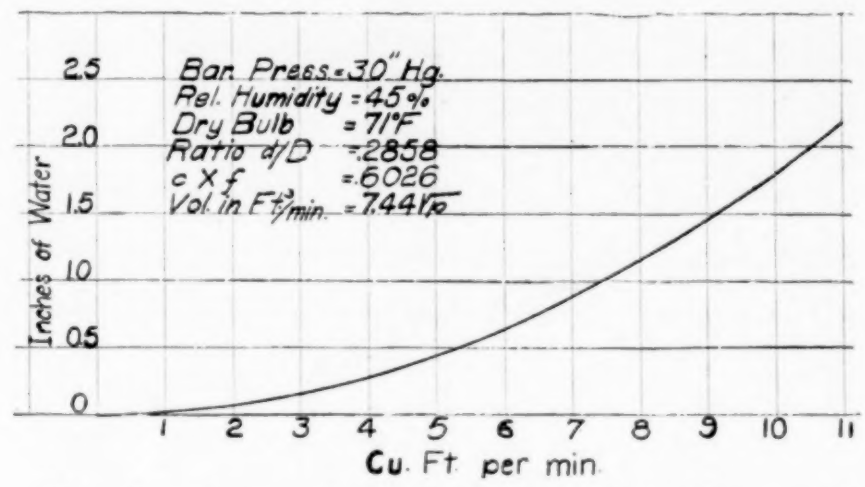

FIG. 2.—Curve of air flow through orifice meter.

the density of the air at the time it passes through the orifice.

Table 1 shows the results obtained by blowing air through the apparatus connected in the following order: the two dust collectors, the orifice meter to which was attached an extra length of tubing, and the gas-meter. Table 2 shows the results of drawing air through the same arrangement of apparatus. The orifice meter and the gas-meter were then interchanged with no appreciable difference in results. When the collectors, which have a combined resistance of about 1½ inches of water, were placed between the two meters, the results were 5 to 10 per cent. in error.

For a working curve we use the air density given in Figure 2. Variations in relative humidity can be ignored but variations in temperature greater than 15° F. are corrected for from standard tables of air density. A U-tube manometer half filled with colored distilled water containing a trace of caprylic alcohol is used in place of an Ellison draft

gage, since it is entirely visible and can be quickly refilled. A white celluloid chart, constructed from the curve for the rate of flow, reads cubic feet per minute directly. The slope of 1:3 used in our manometer is a purely arbitrary one. Our tests showed that the limit of accuracy of the meter was governed primarily by the manometer. For slower air flow, therefore, we use a slope of smaller angle and a lighter liquid in order to increase the excursion in the manometer. For rates of 9 to 10 cubic feet per minute, the manometer shown is satisfactory.

TABLE 1.—CALIBRATION OF ORIFICE METER AGAINST RECORDING GAS-METER

Corrected Gas-Meter Reading	Orifice Meter (From Curve)	Difference
cu. ft. per min.	*cu. ft. per min.*	%
5.04	5.00	—0.8
6.51	6.50	—0.2
7.55	7.50	—0.7
8.34	8.50	+1.9
9.55	9.50	—0.5
10.05	10.00	—0.5

Order of apparatus: compressed air supply, two collectors, orifice meter, and gas-meter.

Buckingham (87) has shown that orifices with a trumpet-shaped entrance are more accurate than flat ones such as we use. The reason for this is the change in the coefficient of discharge occurring with change in the pressure ratio on the two sides of the orifice, a correction which does not appear to be applied by Bailey. While we have used the trumpet-shaped orifices and have found them very accurate, they are difficult to make. The flat orifice, which can be made very easily and with assurance of the same degree of accuracy shown in Tables 1 and 2, gives a method of measuring air flow sufficiently accurate for our purposes.

VIII. Calibration of Apparatus

Figure 3 shows the set-up used in determining the efficiency of the apparatus against fine talc and silica dusts. Since the essential part of the apparatus is the collectors, it is more convenient to blow the air through than to draw it. The air can then be filtered, humidified, heated, or cooled without the use of a powerful pump, while the two needle valves give a control of air flow far more constant than is required. In the Palmer apparatus the air flow is somewhat pulsating, even when air is blown through, owing to the nature of the bubbling. With a single collector on our apparatus this effect is barely noticeable, but with two collectors the pulsations are too slight to be noted on the manometer. This slight pulsation effect is not stopped by using constant air flow but it seems too insignificant to warrant the use of a regulating device such as was employed by the Bureau of Mines.

TABLE 2.—CALIBRATION OF ORIFICE METER AGAINST RECORDING GAS-METER

Corrected Gas-Meter Reading	Orifice Meter (From Curve)	Difference
cu. ft. per min.	*cu. ft. per min.*	%
5.08	5.00	—1.6
6.60	6.50	—1.5
8.06	8.00	—0.8
9.03	9.00	—0.3
9.53	9.50	—0.3

Order of apparatus: two collectors, vacuum pump, orifice meter, and gas-meter.

In the set-up shown, the main air supply enters by the larger of the two needle valves, passes through an empty 5-gallon bottle and then through another 5-gallon bottle stuffed full of dry cotton for filtering the air, and enters the top of the small dust floater where it meets and picks up an ascending cloud of dust.

The intensity of the latter is controlled by the bell clapper and by the small needle valve, which allows the air to pass through the sulphuric acid drying bottles to the bottom of the floater. Sulphuric acid is used in place of calcium chloride to avoid the introduction of dust into the floater. For some time we used the usual type of sensitive glass flow meters for obtaining like air flows at the bottom of the floater, but after a little practice it was found that the position and frequency of the bell clapper had far greater effects on the constancy of dust clouds than did variations in air speed.

The weight of dust introduced was determined by weighing the floater and dust before and after each run. By using tares there is no difficulty in obtaining these weights to the fourth decimal place. The short tube projection from the first collector to the floater is soldered to the collector with Dekotinsky cement, and any dust which lodges in it is added to the first collector. The dusty air enters the first collector where the greater portion of the dust is caught, usually about 95 per cent. or over, and thence passes to the second collector where it is further freed of dust but at an efficiency distinctly lower than in the first collector. The exhaust air, which still contains a trace of dust, passes out through the orifice meter and then through an extra length of tubing in which the degree of humidification is determined by means of a wet and a dry bulb thermometer.

This set-up may sometimes be changed to permit the use of a third collector as a humidifier and dehumidifier, for which purpose a third large bottle may be placed in parallel so that any desired fraction of the air can be passed through the collector before the air reaches the dust floater. It was also found convenient to substitute a hair hygrometer for the first set of wet and dry bulbs. Since attempts to dry volumes of air as large as 8 to 10 cubic feet per minute are impractical with this set-up, and since freezing is too expensive, we were unable to make enough runs with dry air to show whether the dryness of the air had an appreciable effect on the efficiency of the apparatus. A few runs with slower rates of air flow and drying with calcium chloride, however, indicated an increased efficiency and also showed that in dry atmospheres the efficiency of the first effect of the tandem collector was lower than in moist atmospheres. We have not, however, obtained sufficient data to establish this point definitely.

1. *Washing Collectors.*—For cleaning out dusts such as talc and silica, 50 per cent. alcohol is used, as it wets glass and bright nickel more readily than does water, and consequently washes off the dust more rapidly. Stronger solutions and a mixture of ether and alcohol are not sufficiently more effective to warrant their use. In routine work, either in the field or laboratory, a 250-c.c. beaker or flask has more than ample capacity to hold the contents of one collector with its wash water.

2. *Evaporation and Filtration.*—Though it is probably a matter of individual taste, there is no apparent advantage in filtering suspensions such as silica or talc if a large number of samples are to be taken. By running a tare made up of the same liquid and equal in volume to the unknowns, errors from impurities in the collector water or wash water are avoided. This often permits the use of tap water in the field. In the laboratory calibrations recorded in this paper, frequent checks on the

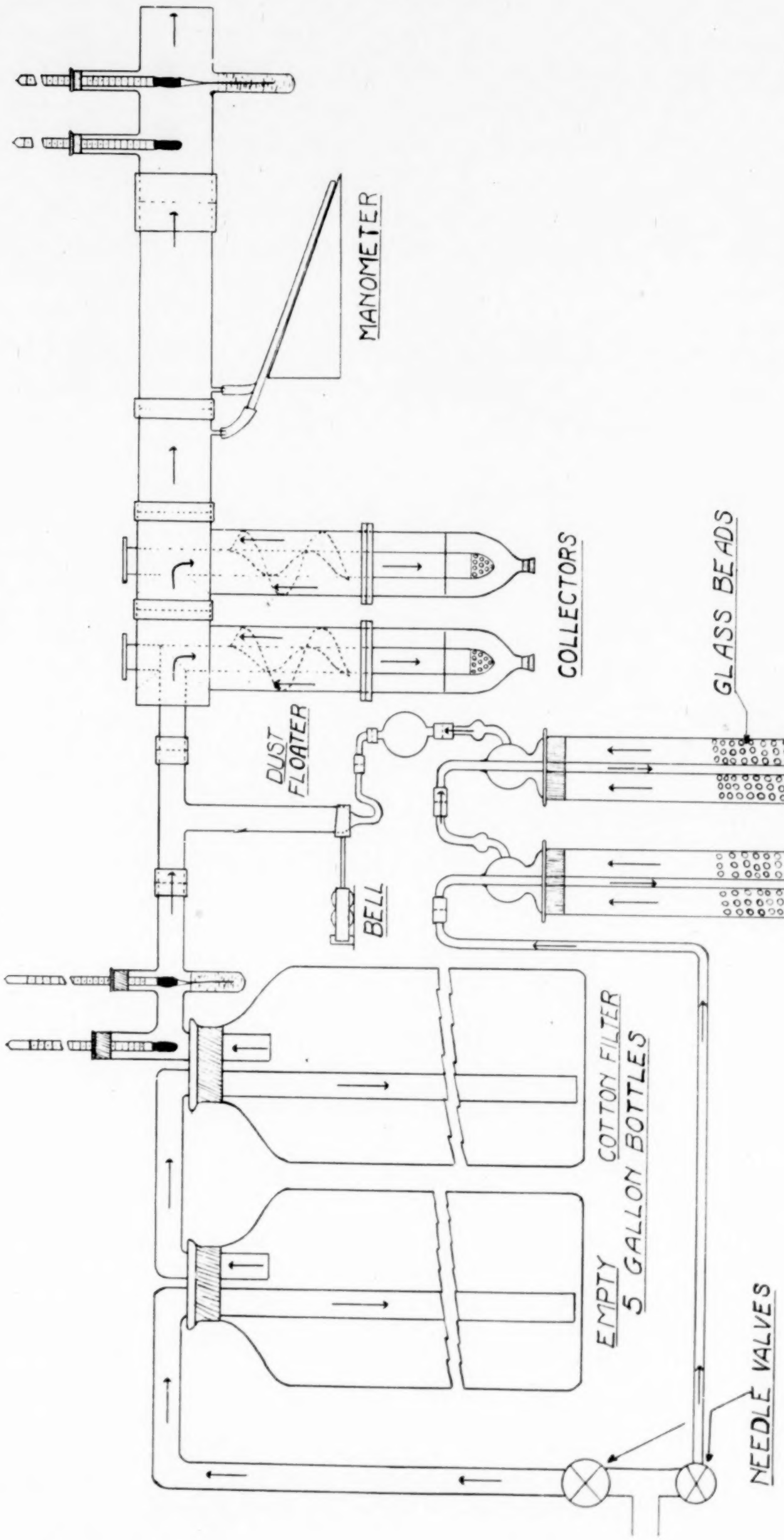

FIG. 3.—Arrangement of apparatus for calibrating dust collectors.

difficulty of obtaining complete dryness were made by introducing definite amounts of talc or silica dust into a beaker, thoroughly wetting the dust, and observing the time required to come to constant weight.

IX. Discussion

After a large number of tests on various dusts with one collector, it was decided to use two, principally in order to see what fraction of the dust missed by the first collector would be caught in the second, and also to discover whether an index of their individual or combined efficiency could be obtained from the ratio of the weights of dust caught in the two collectors. Suppose we make the unwarranted assumption that the two collectors function at exactly equal efficiencies, and then plot theoretical curves of which the ordinates are efficiencies and the abscissae are the ratios of the weights of dust obtained in the two collectors. The equation of the curve for the efficiency of either collector will be 1—B/A, and of the two in tandem will be $1—B^2/A^2$ (Fig. 4)[1], A and B representing the weight of dust caught in the first and second collectors respectively.

In both cases the curves are asymptotic to 100 per cent. efficiency when the ratio of A/B = infinity, or when the first collector stops all the dust and the second gets none. Since we know the weight of dust introduced and can determine the two unknowns, A and B, it is possible to estimate the errors made by assuming that the two collectors function at equal efficiencies. If it can be shown in the laboratory that the single and tandem collectors function at an efficiency of which the ratios A and B furnish an accurate representation, it should then be possible to estimate with reasonable assurance the error in the weight of dust collected in either one or two collectors in the field.

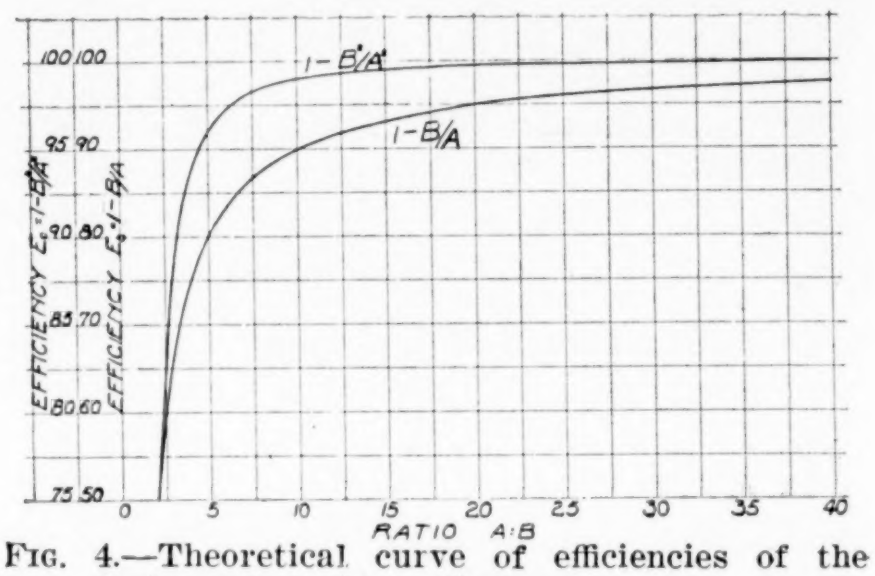

Fig. 4.—Theoretical curve of efficiencies of the single and double collectors.

A large number of laboratory determinations made by the set-up shown in Figure 3 indicate, however, that the efficiencies of the second collector are always substantially lower than those of the first, and that this difference varies markedly with the dust. Tables 3, 4, 5, and 6 show that an error of less than 1 per cent. would be made by this method with talc dust, while silica dust (Tables 7 and 8) gives errors of nearly 3 per cent. In all cases the efficiencies shown are on the basis of weights recovered.

J. I. H.
June, 1923

[1] The derivation of these formulae is as follows:
Let x be the total weight of the sample.
Let A and B be the weights recovered in the first and second collectors, respectively.
Let E_s and E_c be the efficiency of the single and the double collectors, respectively.
Then a single collector will stop an amount:

$$A = E_s x \qquad \text{or} \qquad x = A/E_s$$

and the second collector will stop:

$$(x—A)\ E_s = B \qquad \text{or} \qquad x = A+B/E_s$$

Eliminating x,

$$E_s = 1—B/A$$

The combined efficiency of two collectors would be

$$\frac{A+B}{x} = \frac{A+B}{A/E} = \frac{A+B}{A} \times \frac{A—B}{A}$$

$$= \frac{A^2—B^2}{A^2}$$

$$E_c = 1—B^2/A^2$$

Occasionally an efficiency of over 100 per cent. is obtained, while more rarely a recovery of less than 90 per cent. is made in the first collector. These figures have been purposely omitted, however, while those given are believed to be representative and were chosen at random from a large number of determinations.

The probable explanation of the discrepancy in the efficiencies of the first and second collectors is that the greater part of the dust is removed in the first and, in order that the dust passing through the second may have a like chance of being wetted, it must pass out of the second thimble in bubbles which are correspondingly smaller. It would therefore seem advisable to use thimbles with smaller holes in the second collector than are used in the first.

TABLE 3.—TALC DETERMINATIONS: NO SCRUBBER PLATE USED AND COLLECTORS WASHED WITH 50 PER CENT. ALCOHOL

Dust Concentration	Time	Efficiencies			Ratio First : Second
		Total	First Collector	Second Collector	
mg. per cu.ft.	*min.*	%	%	%	
14.03	15	99.1	95.4	80.3	26.4
13.3	17	99.1	94.2	82.5	21.3
13.3	15	99.4	95.5	85.1	24.7
13.8	15	99.0	95.2	78.0	25.0
16.0	15	98.9	95.1	78.3	25.1
20.3	12	97.9	93.9	65.1	23.3
12.1	16	99.1	94.5	83.5	20.6
13.3	15	99.5	95.5	87.6	23.9
9.1	15	99.7	94.9	93.0	20.0
12.2	15	99.5	95.3	90.1	22.6
Average...		99.1	95.0	82.4	23.3
Theoretical		99.81	95.7	..	..

TABLE 4.—TALC DETERMINATIONS: SCRUBBER PLATE USED AND COLLECTORS WASHED WITH 50 PER CENT. ALCOHOL

Dust Concentration	Time	Efficiencies			Ratio First : Second
		Total	First Collector	Second Collector	
mg. per cu.ft.	*min.*	%	%	%	
14.1	15	99.9	96.7	95.9	30.1
13.6	15	98.7	95.8	71.4	32.2
13.7	15	99.1	95.6	40.7	26.5
13.5	15	98.6	94.8	73.1	24.5
12.5	15	99.2	95.6	82.1	26.6
16.3	12	99.3	95.7	83.2	26.8
16.3	14	99.4	95.9	83.8	27.7
13.5	13	99.5	96.0	87.1	28.4
13.2	15	99.3	95.5	84.1	25.7
12.3	15	99.3	95.8	84.1	27.2
19.3	11	99.0	95.4	77.9	26.5
Average...		99.2	95.7	82.1	27.5
Theoretical		99.86	96.4	..	..

1. *The Size Distribution of Dust Particles in the Double Collector.*—Talc and silica dusts were chosen for this work—talc because it has been found to pass through the Palmer apparatus in unexpectedly large amounts, and silica because it has been used by other investigators. Of the two dusts, talc showed by far the more uniform particles. Photomicrographs of the original dusts prepared by Green's (30) method and direct measurements with 500 and 1,000 diameters magnification showed that most of the talc particles were under 15 microns, while the silica (obtained from the Corning Glass Company) showed no uniformity in particle size, many particles being as large as 40 microns or more. On the other hand, however, the silica contained a decided excess of fine particles measuring 1 micron and less. The talc is much lighter and more fluffy than is silica, and has a correspondingly greater tendency to flocculate. It is essential to use dry air in producing talc dust clouds, otherwise the particles form small balls and clumps which are not broken up by the current of air or by the rapping of the bell clapper.

Samples of silica dust taken at the mouth of the floater showed particles distinctly smaller than those of the original dust. This indicates that there is a

preferential floating of the small particles. Microscopic examination of the suspensions from the two collectors, without the addition of stabilizers, showed clearly that the particles in the first collector were smaller than those of the original dusts. In the case of silica they were rarely over 15 microns, while

TABLE 5.—TALC DETERMINATIONS: SAPONIN USED AND COLLECTORS WASHED WITH ETHER AND ALCOHOL

Dust Concentration	Time	Efficiencies			Ratio First : Second
		Total	First Collector	Second Collector	
mg. per cu.ft.	*min.*	%	%	%	
14.7	15	99.2	95.1	83.4	23.6
14.0	15	99.5	95.3	84.0	24.4
15.5	14	99.6	95.3	82.4	24.5
16.1	14	99.3	95.2	85.1	23.5
14.5	15	99.0	95.4	85.0	24.5
Average...		99.3	95.3	84.0	24.1
Theoretical		99.8	95.8	..	..

TABLE 6.—TALC DETERMINATIONS: NO SAPONIN USED AND COLLECTORS WASHED WITH ETHER AND ALCOHOL

Dust Concentration	Time	Efficiencies			Ratio First : Second
		Total	First Collector	Second Collector	
mg. per cu.ft.	*min.*	%	%	%	
13.8	14	99.3	95.7	85.0	25.8
14.5	14	99.8	96.5	92.3	28.4
18.3	12	98.2	95.8	56.1	39.8
14.1	15	99.1	95.4	80.9	26.2
23.9	10	98.6	95.1	69.8	28.1
Average...		99.0	95.7	76.8	29.7
Theoretical		99.9	96.6	..	..

those from the talc were mostly under 10 microns. On the basis of count or size-frequency, the small silica particles were in great excess over the large ones, most of them exhibiting pronounced brownian movement. In the second collector, the presence of silica particles too large to show brownian movement is rare, the majority being 1 to 2 microns and less. This is true of talc particles also, except that in the presence of water alone they show a pronounced tendency to flocculate into clumps which are too large to show brownian movement.

While the silica particles caught in the second collector are of about the same size as the talc particles, the fact that they are more dispersed may account for the relatively lower efficiency of the second collector for the silica than for talc. The presence of flocculates in the dust clouds tends to facilitate wetting, as the flocculated mass is more readily retained in the collector than is an equivalent amount of dispersed particles. Our evidence is insufficient to show definitely the relation between particle size and the readiness with which the particles can be wetted, although present results support the explanation of the Bureau of Mines—namely, that the efficacy of wetting methods decreases with the size of the particles. This, however, depends largely on the dispersion of the dust cloud. There is no doubt that the efficiency of the second collector can be increased by decreasing the size of the thimble holes. After the greater part of the dust has been eliminated by the first collector, the use of a second, especially adapted to catching the small particles and employing possibly some wetting medium other than water, seems to offer a logical solution. We wish to emphasize the point that the gravimetric error made by not catching these small particles is about 2 to 3 per cent. of the total dust sample, so that their gravimetric significance is questionable although their number may be high. It is shown in the case of both talc and silica dusts that the scrubber plate gives an

increased efficiency too slight to be of value. Comparison of the results with and without the scrubber plate indicates that the greater part of the dust is caught by the bubbling action through the thimble holes and that only a small fraction is stopped by subsequent bubbling through the water above.

TABLE 7.—QUARTZ DUST DETERMINATIONS: NO SCRUBBER PLATES USED

Dust Concentration	Time	Efficiencies			
		Total	First Collector	Second Collector	Ratio First : Second
mg. per cu.ft.	*min.*	%	%	%	
49	12	98.0	95.6	56.0	38.8
40	15	98.1	95.2	60.0	33.1
39	15	97.8	95.2	53.2	36.8
42	15	97.8	94.7	50.4	41.5
Average...		97.9	95.2	54.9	37.6
Theoretical		99.92	97.08	..	..

TABLE 8.—QUARTZ DUST DETERMINATIONS: SCRUBBER PLATES USED

Dust Concentration	Time	Efficiencies			
		Total	First Collector	Second Collector	Ratio First : Second
mg. per cu.ft.	*min.*	%	%	%	
61	10	98.98	95.7	69.2	40.7
57	12	99.70	96.2	52.4	47.5
55	12	97.15	94.7	45.9	38.2
43	15	97.40	95.2	46.6	40.6
Average...		98.3	95.5	53.5	41.8
Theoretical		99.95	97.28	..	..

Comparative tests of talc dust with and without saponin show results too nearly alike to warrant drawing conclusions. The fact that the presence of ether and alcohol or of 50 per cent. alcohol alone facilitates cleaning is likewise difficult to show by figures, and depends too much on the personal equation. There is no reason to suppose that these are the best liquids with which to wash all powders off glass or nickel. There are doubtless others which will dislodge certain dusts with greater ease, but for many dusts they are of undoubted help and need be used in only small amounts. By using like amounts in the tare, corrections are made for impurities in the ether and the alcohol.

2. *Comparison with Greenburg and Smith's Method.*—This method (75) though not published in detail, appears to be much like ours and is, therefore, of especial interest since it confirms quite independently the general principles which we believe are established. Instead of a collector tube such as ours, they use a flat-bottom glass container. Their air entrance tube is 5/8 inch in diameter and enters the collector through one hole of a two-hole stopper. The bottom of the entrance tube, which is flat and pierced by fifteen holes 0.8 mm. in diameter, is kept 0.8 mm. from the bottom of the collector by lugs. Since 300 c.c. of water are placed in the collector, the depth of the water is probably greater than in our apparatus, while the air flow must be far less. The escape air passes out through the other hole of the rubber stopper by way of the suction pump and flow meter, presumably somewhat as in our apparatus. No air speeds are given, and this makes it impossible to compare the capacities. This, however, is of less importance for purposes of comparison than the principle to which they ascribe the 96 per cent. gravimetric efficiency obtained with fine silica dust. Their method of calibration is that used by the Bureau of Mines for the sugar-tube calibrations, and this is the method used by us, also, except that we evaporate the collected dusty water while they presumably filter off the dust and obtain the weight by ignition. With pure silica dust, however, this should cause no appreciable difference, though their results

may be slightly lower owing to the difficulty in filtering fine silica suspensions, mentioned by the Bureau of Mines (66). The point which particularly interests us is their claim that the efficiency obtained is due to the combined effect of impingement and bubbling through the water. As has already been pointed out, we found no advantage in placing the thimble of our entrance tube close to the bottom of the collector tube, while they particularly emphasize the necessity of doing this. They must use some method of holding the entrance tube in position, however, as it would otherwise be too unsettled and probably cause leaks at the rubber stopper. In our apparatus the spiral holds the tube firmly in position, though this was not the reason for adopting the spiral.

Our conception of impingement postulates velocities comparable to that at the orifice of the Kotzé konimeter—namely, 30 to 130 meters per second. Assuming 135 holes 0.06 inch in diameter in our thimbles (see Fig. 1), a flow of 10 cubic feet per minute, and uniform flow through the holes (which is ignoring the orifice effect and not strictly accurate), the velocity at the thimbles on the outlet side is approximately 19 meters per second—an amount which is appreciably less than is possible on the konimeter. To obtain air speeds which substantially exceed this, it would seem that Greenburg and Smith either require very powerful suction or else must blow the dusty air through under pressure. In either case our experience shows that water will be blown out of the top of the collector unless it is wide and high, or unless very small air volumes are used.

It is perhaps drawing ultra-fine distinctions, but we should ascribe the high efficiencies obtained by Greenburg and Smith to the size of the holes and the consequent small size of the bubbles produced rather than to impingement. Undoubtedly the velocity of the air and the abrupt and complete change in direction, more complete in their apparatus than in ours, have much to do with catching the dust. The holes in our thimbles (Fig. 1) are nearly twice the diameter of the holes in theirs, and there are relatively more of them. The total area of the holes in our case represents about half the area of the entrance tube, while in their instrument the ratio is much less. Their entrance tube is 5/8 inch in diameter and 9 inches long, while ours is 1 inch in diameter and 14¾ inches long. The difficulty of cleaning the two tubes is probably about equal; their holes are smaller, while our tube is longer. In field work particularly we have found cleaning the thimble the only objectionable part of the technic and for that reason we have occasionally used thimbles with one large hole (measuring about 1/8 inch) at the tip. By using smaller holes in the thimble we undoubtedly obtain better wetting owing to more intimate contact, but this advantage is counterbalanced by the increased difficulty in cleaning. While our thimble is detachable, as is also the bottom portion of the collector, matters are considerably simplified if the thimble need not be removed.

From our experience a device for avoiding entrainment losses is essential; otherwise slow air speeds must be used which cut down the efficiency of the apparatus and result in samples comparable in size and rate with those used in filtration methods. In our opinion this annuls the chief advantage of wetting methods.[2]

[2]Some time after the writing of this paper we received, through the courtesy of Mr. S. H. Katz

X. The Adaptation of Collector to Field Use

When a determination is made in the field by methods of direct filtration, such as the sugar tube or cotton filter, the filter may be sent back to the laboratory by mail for examination. No washing is necessary in the dusty atmospheres usually prevailing. In our opinion, these facts give filtration methods a decided advantage. With our apparatus, and the same objection presumably applies to that of Greenburg and Smith and to the Palmer instrument, a certain amount of simple but careful technic is required in washing the several parts of the collectors. Greenburg and Smith make the practical suggestion of sending the main collector tube to the laboratory but propose washing the removable parts in the field—an operation which we have found objectionable.

Another decided advantage of filtration methods is the use of long flexible rubber tubing for connecting the filter

TABLE 9.—SUMMARY OF TABLES 1 THROUGH 6

Substance	Efficiencies					Ratio	Remarks
	By Weight			Theoretical			
	Total	First Collector	Second Collector	Total	Single Collector	First : Second	
	%	%	%	%	%		
Talc	99.1	95.0	82.4	99.8	95.7	23.3	No scrubber plate used and collectors washed with 50 per cent. alcohol
Talc	99.2	95.7	82.1	99.86	96.4	27.5	Scrubber plate used and collectors washed with 50 per cent. alcohol
Talc	99.3	95.3	84.0	99.8	95.8	24.1	Saponin used and collectors washed with ether and alcohol
Talc	99.0	95.7	76.8	99.9	96.6	29.7	No saponin used and collectors washed with ether and alcohol
Quartz	97.9	95.2	54.9	99.92	97.08	37.6	No scrubber plate used and collectors washed with ether and alcohol
Quartz	98.3	95.5	53.5	99.95	97.28	41.8	Scrubber plate used and collectors washed with 50 per cent. alcohol

of the Bureau of Mines, one of their newest impingers. The construction of this is such that the difficulty in clearing out the dust which collects on the inside of the bottom of the ⅝ inch perforated tube is probably obviated. It is understood that the Bureau of Mines' work on the new impinger is soon to be described.

and the pump so that the filter can be set up in any location which seems desirable. We are combining several of these ideas, which are especially appealing from the practical standpoint, by connecting one or two collectors, in series or in parallel, to the pump by long rubber tubing. If all parts of the collectors are made of thin standard nickel-plated brass tubing or of spun copper sheets, and if the same size entrance tube with suitable thimble is used, the entire collector can be detached from the rubber tubing, stoppered, and taken to the laboratory. This avoids the washing otherwise necessary in the field and permits the use of an adequately powerful pump and suitable air meter, the accuracy of which is in no way impaired by the use of long rubber tubing on the up-stream side of the pump. Twelve all-metal collectors have been made and will be tried out in field tests against an electric precipitator.

A practical objection to the use of our apparatus in the field is the temperature limitation imposed by the use of water as the wetting medium—an objection which was not encountered in the laboratory. If the air entering the first collector is dry, regardless of its temperature, evaporation is rapid and the cooling effect considerable. A thermometer in the bottom of the first collector registers the wet bulb temperature fairly accurately, so that the water freezes when the wet bulb temperature reaches 32° F. While the presence of soluble matter will depress the freezing point, we have had the first collector freeze in factories when the dry bulb temperature registered 41° F.—a temperature which is often encountered in the vicinity of Boston, during the winter months, in portions of buildings where there is no especial need of heat. Without any warning, ice crystals formed on the scrubber plate and thimble with the result that the air flow dropped from 10 cubic feet to 1½. The second collector, on the other hand, did not freeze since the air entered it at approximately the saturation point and therefore had less evaporative power and less cooling effect. This defect of freezing can probably be obviated by the use of an anti-freezing agent which will not appreciably increase the viscosity.

The apparatus is unsuited for determining such particulate matter as smokes and most fumes, but since it is not necessary to take as large samples of these substances we do not consider this an objectionable feature, and use electric precipitation or dense filters instead. More for curiosity than to test its efficiency we recently attempted to use this new apparatus for determining hydrochloric acid gas in the air. The concentration of acid was so low that it required about 8 to 10 liters in order to obtain amounts which could be determined, even approximately, with 0.05 N acid and alkali by the usual methods of aspiration and titration in the presence of sensitive indicators. To avoid corrosion a glass entrance tube was used and holes blown in the end, much the same as in Greenburg and Smith's collector. The spiral was soldered on a brass tube, slipped over the entrance tube, and paraffined. Air flows up to 5 cubic feet per minute were used and samples which could be titrated with N/10 solutions were obtained in a few minutes. The results were uniformly lower than by aspiration in the usual manner. For still lower concentrations of acid, such as 1 part per million, the error was greater. Since established methods of hydrogen-ion concentration are quite suitable for such work, the use of our apparatus for

this problem was investigated no further.

1. *The Amount of Air Required for a Representative Sample.*—The rate at which our apparatus, in its present form, functions is 8 to 10 cubic feet per minute, which is quite adequate for the purposes outlined. There is no reason to believe that 10 cubic feet per minute will always suffice. Rather than increase the size of the pump it would be better to use two single collectors in parallel or two separate outfits such as have been described. For smaller samples, which presumably signify finer particles, we should use the collectors as they stand and decrease the size of the thimble holes. If smaller collectors are used, the amount of water required is correspondingly decreased and it is possible, often, to clarify the dusty water by centrifuging in a laboratory apparatus and thus to estimate the amount of dust by the volume occupied in the centrifuge tube—a method which is frequently used in routine chemical analyses.

XI. Summary

Following a classification of atmospheric particulate dust on the basis of particle size and dispersion, the literature on methods for its determination is reviewed. The theory of wetting dust and other fine particles is discussed in its relation to industrial and laboratory methods of recovering particulate matter from the air. Laboratory methods of producing dust clouds are described in their relation to particle size and tendency to flocculate. The effect of foam producing agents, such as saponin, on the wetting and collection of dust consists chiefly in facilitating the cleaning of the apparatus.

A new apparatus for the collection and determination of atmospheric dust is described. It consists in a device for passing dusty air through water at a rate of 8 to 10 cubic feet per minute. The degree and duration of contact between the dusty air and the wetting medium are controlled by the air speed and by a perforated thimble immersed in water. The holes in the thimble illustrated are 0.06 inch, but this is not a fixed dimension. Entrainment losses are avoided by spiraling the exhaust air out of the collector and thus changing its direction. A vacuum cleaner motor-fan serves as the source of suction and is equipped with a rheostat for speed control. An orifice meter at the exhaust measures air flow.

For laboratory use a portion of the collector is made of glass but the greater part is of nickel-plated tubing or of spun sheets. For field use all-metal collectors are proposed.

The apparatus is calibrated against air-floated clouds of fine silica and talc dusts. It is shown that the combined efficiency of two collectors in series varies from 97 to 99 per cent. with these two dusts. The first collector recovers about 95 per cent. of the dust, which consists of practically all the particles greater than 10 microns and the larger portion of those less than 10 microns. The efficiency of the second collector is substantially lower and varies from 50 to 85 per cent. with talc and silica dusts. The dust recovered in the second collector consists of much smaller particles, most of which are about 1 to 2 microns or less and show brownian movement. The difference in the efficiencies of the two collectors is explained by the fact that the first removes about 95 per cent. of the dust so that their respective tasks are not comparable. It is suggested that

the second collector be equipped to give more intimate contact between the dusty air and the wetting medium than does the first.

For field use all-metal tandem collectors connected to the suction pump by rubber tubing are proposed.

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BOOK REVIEWS

INDUSTRIAL HYGIENE AND MEDICINE. By *E. W. Hope*, O.B.E., M.D., D.Sc., Medical Officer of Health for the City and Port of Liverpool; Professor in Public Health, University of Liverpool; Late Professor of the Society of Medical Officers of Health, and Late Examiner in the Society of Medical Officers of Health, and Late Examiner in the Universities of Belfast, Cambridge, Edinburgh, and Manchester, and to the Royal College of Physicians (Lond.), and Royal College of Surgeons (Eng.); in collaboration with *W. Hanna*, M.A., M.D., D.P.H., and *C. O. Stallybrass*, M.D., D.P.H., Assistant Medical Officers of Health for the City and Port of Liverpool, and Lecturers in Public Health Subjects, etc., University of Liverpool. Cloth. Pp. 766 with introduction, illustrations, appendix, and index. London: Baillière, Tindall & Cox; New York: William Wood and Company, 1923.

The appearance of this new textbook is welcome; it marks the rapid advance which has been taking place in the science of industrial medicine. No reader can fail to note the fact that in the last few years new knowledge has been acquired on every side. The physiology and practice of ventilation, and the standards and methods of illumination have been revolutionized; study of activity and fatigue has affected working hours, working spells, and rest-pauses; the doctor is being called in to prevent as well as to treat disease and accidents: the demand for industrial canteens, washing accommodations and drinking water has led to the production of new appliances. Meanwhile study of dust phthisis is throwing light on general tuberculosis, and the occurrence of cancer among tar workers has led to the experimental production of cancer in animals.

The whole field may be conveniently subdivided into three portions: one concerned with the prevention of ill health, that is to say, with maintaining the vigor and activity of workers; a second with the occurrence and cure of occupational disease; and a third with the medicolegal aspects of compensation acts. Each of these subdivisions is worthy of a separate book, and indeed has been accordingly dealt with; yet Dr. Hope and his co-authors have essayed the labor of combining all in one book. For this purpose free drafts have been made on existing literature; much information has been conveniently brought together from government reports and scientific journals. The result on the whole is good, and a useful book for students has been produced. Perhaps at times the eager spirit underlying industrial investigation is missing, and the reader feels that the story is being told as if it were second hand, rather than by those in immediate contact with workers and their work; still there is hardly one of the eleven chapters which is not well and concisely written, and each possesses a valuable bibliography (reference number 12, Chapter 11, however, seems not to have been authenticated).

Particular attention is given to dust as a cause of disease, and also to occupational tuberculosis; these subjects meet in tuberculous silicosis. The data are well presented and are entirely up-to-date. Here, as elsewhere, the writers are content to present the views of others rather than to suggest new light. Cancer as an industrial disease is not so well dealt with; there are several omissions, particularly the absence of reference to the occurrence of scrotal cancer among mule-spinners. One of the best sections is that dealing

with anthrax, as indeed might be expected in view of the special connection of the authors with Liverpool where the new anthrax disinfecting station has been built.

Regret may be expressed that this textbook has appeared almost simultaneously with the Occupational Supplement of the Registrar-General which deals with the years 1910 to 1912, and contains much new information which is probably better based than that published for previous decennia. Through no fault of the authors this coincidence makes many of the mortality rates given already antiquated. The book contains many illustrations, some of which are excellent, although others cannot have much meaning to anyone unfamiliar with the process portrayed.—*Edgar L. Collis.*

SUPPLEMENT TO THE SEVENTY-FIFTH ANNUAL REPORT OF THE REGISTRAR-GENERAL FOR ENGLAND & WALES. PART IV. MORTALITY OF MEN IN CERTAIN OCCUPATIONS, 1910-12. Pp. 100. London: H. M. Stationery Office, 1923.

As long ago as 1851, Dr. Farr published in the Fourteenth Annual Report of the Registrar-General for England and Wales an investigation of occupational mortality. The subject was elaborated for subsequent censual years and there is in existence a unique series of Decennial Supplements. The inquiries were extended in the reports for 1890 to 1892 and 1900 to 1902; and now, although somewhat belated in its appearance, the report for 1910 to 1912 has been issued. It is at once somewhat curtailed and also expanded; curtailed in that the usual commentary by the Medical Superintendent is omitted, and expanded in that some valuable new subdivisions of the occupational groups are given. The volume is composed nearly wholly of tabular matter, 189 individual tables being given. Summary tables are also printed, and comparison is instituted between the mortality rates for 1900 to 1902 and for 1910 to 1912. One useful statistical change has been adopted; in previous reports the mortality figures have been arrived at by establishing first a standard with which each occupation is compared, and the standard taken has been that general male population between the ages of 25 and 65 which, for each decennial period, produced 1,000 deaths. This population of course varied from one period to the next; hence in order to compare the figures of one period with those of another, complicated sums were needed. Now, however, a standard population has been fixed at the figure used for 1900 to 1902, which happened to be 71,005, with a certain distribution according to age.

The report will be seized upon with avidity by everyone interested in industrial hygiene, for, even after every allowance has been made for imperfections due to insuperable difficulties in making the data exact, there remains a wealth of useful information. When the data now published are compared with those of the two previous supplements, there is found marked improvement in practically every occupation; and what is more important, the improvement has on the whole been most marked in those occupations which stood worst in 1900 to 1902, as may be seen in the accompanying figures for a few occupations taken at random (Table 1).

TABLE 1.—COMPARATIVE MORTALITY FOR AGES 25 TO 65 IN CERTAIN OCCUPATIONS IN ENGLAND AND WALES

Trade	1890-1892	1900-1902	1910-1912	
			No.	% decrease[1]
Dock laborers	2,114	1,481	1,127	46.7
Glass makers	1,719	1,493	938	45.4
Stone quarriers ...	1,359	939	792	41.7
Coal miners ..... (South Wales)	1,322	951	777	41.2
Potters	1,970	1,493	1,196	39.3
Printers	1,267	994	773	39.0
Cotton operatives .	1,318	1,114	811	38.5
Agricultural laborers	731	621	470	35.7
Millers	974	890	641	34.2
Brick makers	857	653	567	33.8
Tailors	1,114	1,027	799	30.2
Coal miners ..... (Durham and Northumberland)	894	763	635	29.0
Gardeners	638	563	457	28.4

[1]As compared with years 1890-1892.

When the causes which make up the total mortality are examined in detail, a fall is found to have taken place for all males when compared with the figures of 1900 to 1902, at least with regard to most of the chief causes of death; thus, diseases of the nervous system decreased 17 per cent., phthisis 25 per cent., pneumonia 27 per cent., and bronchitis 36 per cent.; but valvular disease of the heart increased 17 per cent., cancer 15 per cent., and diseases of the digestive system 4 per cent.

The figures for phthisis show that tin miners, with a special exposure to silica dust, stand at the top with a figure of 678, while the clergy are lowest (45); subdivision of the stonemason group shows the sandstone mason with a figure of 415, but the limestone mason with one of 129. The "phthisis-ridden" industries still have high figures: shoemakers, 222; tailors, 186; and printers, 208; but subdivision of the last group shows hand compositors with a figure of 239, and the machine compositors with one of only 70.

Cancer figures vary from 125 for brewers to 41 for lithographers; chimney sweeps are still high (107), but they no longer head the list as of old. Parts of the body affected are not stated, and no useful investigation regarding cancer as influenced by occupation can be made without this additional information. The matter is, we understand, under consideration.

Valvular disease of the heart is highest among seamen (85) and costermongers (72), and lowest among clergy (22) and medical men (23).

Lead poisoning is the only distinctive occupational disease referred to; naturally it appears in only a few occupations. Lead manufacturers stand highest with a figure of 123; next in order come potters (22) and painters (20).

The facts presented in the tables are so numerous, and often of such interest, that no adequate digest can be attempted. Each inquirer must search for himself, and his search is certain to prove of value. Already the period 1920 to 1922 which should be dealt with in the next Occupational Supplement, has passed, and a hope may be expressed that the report will appear before the interest aroused by the present publication has dissipated.—*Edgar L. Collis.*

ANNOUNCEMENT OF

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The Eighth Annual Meeting of the American Association of Industrial Physicians and Surgeons will take place in Buffalo, October 1, 2 and 3 of this year. It will be held in the New Statler Hotel during the same week as the annual meeting of the National Safety Council, and one or more sessions will be in conjunction with the Health Service Section of that organization.

An excellent program is being prepared by the program committee, of which Dr. C. D. Selby of Toledo is chairman.

It is hoped and anticipated that a large number of members will be present at Buffalo. It is fairly central and new territory so far as the annual meeting of our Association is concerned.

Will members of the Association who wish to read papers at this meeting please communicate as soon as possible with Dr. Selby, 655 Spitzer Bldg., Toledo, Ohio.

J. I. H.
June, 1923